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PHASE I REPORT, STUDY TO ESTABLISH ELECTROMAGNETIC COMPATIBILITY SPECIFICATIONS

CONTRACT NO. NAS8-11426
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ABSTRACT

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The problem of automatic checkout of the electromagnetic compatibility (EMC) of large space vehicle systems in an unfavorable electromagentic environment is being considered from the point of view of using those existing component and subsystem tests and criteria or devising tests and criteria in which the data obtained and conclusions drawn may be directly usable in checking the EMC of the assembled vehicle system. Through a combination of analysis and experiment, several potential modifications to traditional interference testing and the associated criteria are under study. These take the form of elimination of redundant testing, revisions to existing tests, and addition of new tests. The detecting problems associated with measuring the parameters of interest are being investigated to a limited extent. All of these considerations are being carried out having in mind the end goal desired, the automation of EMC checkout.

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1. INTRODUCTION

1.1 SCOPE. The scope of this effort is to establish by theoretical analysis and laboratory experiment, realistic electromagnetic compatibility specification procedures and limits applicable to space vehicle systems, which are checked out automatically in a complex facility with a relatively high and variable ambient electromagnetic environment.

The above statement was taken from Appendix A, Statement of Work, Contract No. NAS8-11426. This statement further defines a Phase I consisting essentially of literature study and familiarization with the Marshall Flight Center concepts relating to EMC, terminating in this report of the Phase I activities. Appendix II lists various references that have been helpful as part of the familiarization process. It should be noted that the most useful documents are those about the SATURN systems, usually published by MSFC. In reality the familiarization through use of these documents and visits to Marshall Space Flight Center will continue through this entire program. Documents of no use towards the ends of Contract NAS8-11426 are not listed.

Upon commencement of this study it immediately became apparent that it would not be profitable to spend the entire time in a search for applicable literature in the general field of electromagnetic compatibility. Study of subjects, by nature, within the scope of Phase II have been commenced and reported upon in the monthly reports. In effect this made Phase I a familiarization with SATURN concepts and a commencement of the Phase II tasks. Thus the Phase I report and review become in reality a review of the Phase I and II work done to date and of the direction this study is taking. Upon approval of the Phase I report, Phase II is indicated to commence about five months after go-ahead leading immediately to the task described in Paragraph 1.1 above.

1.2 PHASE I REPORT. This report describes certain analytical and experimental work done as the initial stages of the establishment of an "Electromagnetic Compatibility Specification" for SATURN V. The effort bears directly on problem areas in the use of traditional approaches and specifications. In part, Phase I has been an attempt to define the Phase II task which appears to be essentially as stated in the contract work statement. In the latter portion of this Phase I report, an indication is given of activities for the near future.

2. SOME PROBLEMS ASSOCIATED WITH TRADITIONAL EMI CONTROL SPECIFICATIONS

2.1 COMPARISON OF INTERFERENCE AND SUSCEPTIBILITY SPECIFICATION CRITERIA.

Interference limits as used today must be considered to be arbitrarily set though they may have been initially related to communications equipment sensitivities in the World War II era. Susceptibility limits seem to be objective in the sense that it appears an attempt was made to choose limits above the level of expected interference. That this goal was only partially attained and the data obtained is of limited usefulness is shown in a later part of this report.

2.1.1 Comparison of Some Levels in MIL-I-6181D and MSFC Specification No. 279. These two specifications have been selected for comparison since the former has governed SATURN component procurement and is in many respects similar to most specifications in use over the last few years and the latter is a recent specification prepared by MSFC and may supercede MIL-I-6181D at some future date. In addition, MSFC No. 279 is quite similar to the recently issued MIL-STD-826.

Figure 1 compares susceptibility voltage criteria and interference voltage criteria for CW power line conduction as given in the above two specifications. It should be noted that the strange interference criteria given for the range of frequencies below 150 KHz were arrived at by converting the current criteria (MSFC 279, Figure 6) to a voltage criteria assuming a hypothetical 50 ohm LSN network (this comparison is, no doubt, of little value). The susceptibility voltages vary from approximately 40 to 70 db above a microvolt more than the interference voltages supporting the statement made in Paragraph 2.1 (over the range of known LSN impedance). However, one must realize that this comparison is of limited usefulness for the actual interference currents measured and the currents resulting from a susceptibility test depend upon the configuration of equipments used and their impedances.

Figure 2 is included as a matter of interest to facilitate bridging the gap of switching ones thinking from voltage to current. Both MIL-I-6181D and MSFC 279 give interference current and voltage criteria over the region from 150 KHz to 25 MHz. Using the LSN impedance curve, Figure 2, MIL-I-6181D, one may show the equivalence of the voltage criteria (Figure 7, MIL-I-6181D, and Figure 3, MSFC 279) and the current criteria (Figure 9, MIL-I-6181D and Figure 7, MSFC 279).

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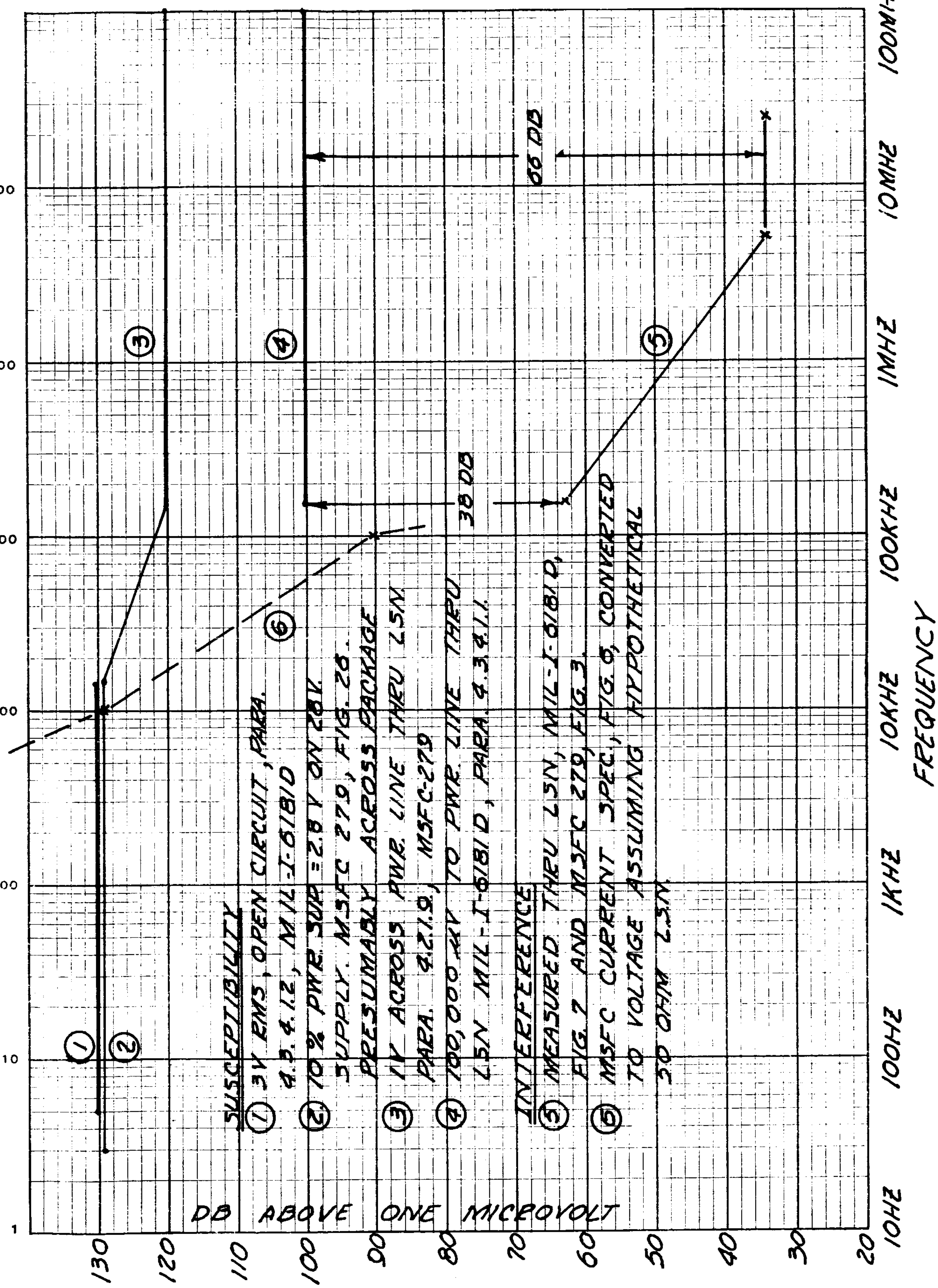

SEMI-LOGARITHMIC 359-96 KEUFFEL & ESSER CO. 7 CYCLES X 60 DIVISIONS

FIGURE 1. COMPARISON OF INTERFER. & SUSCEPT.

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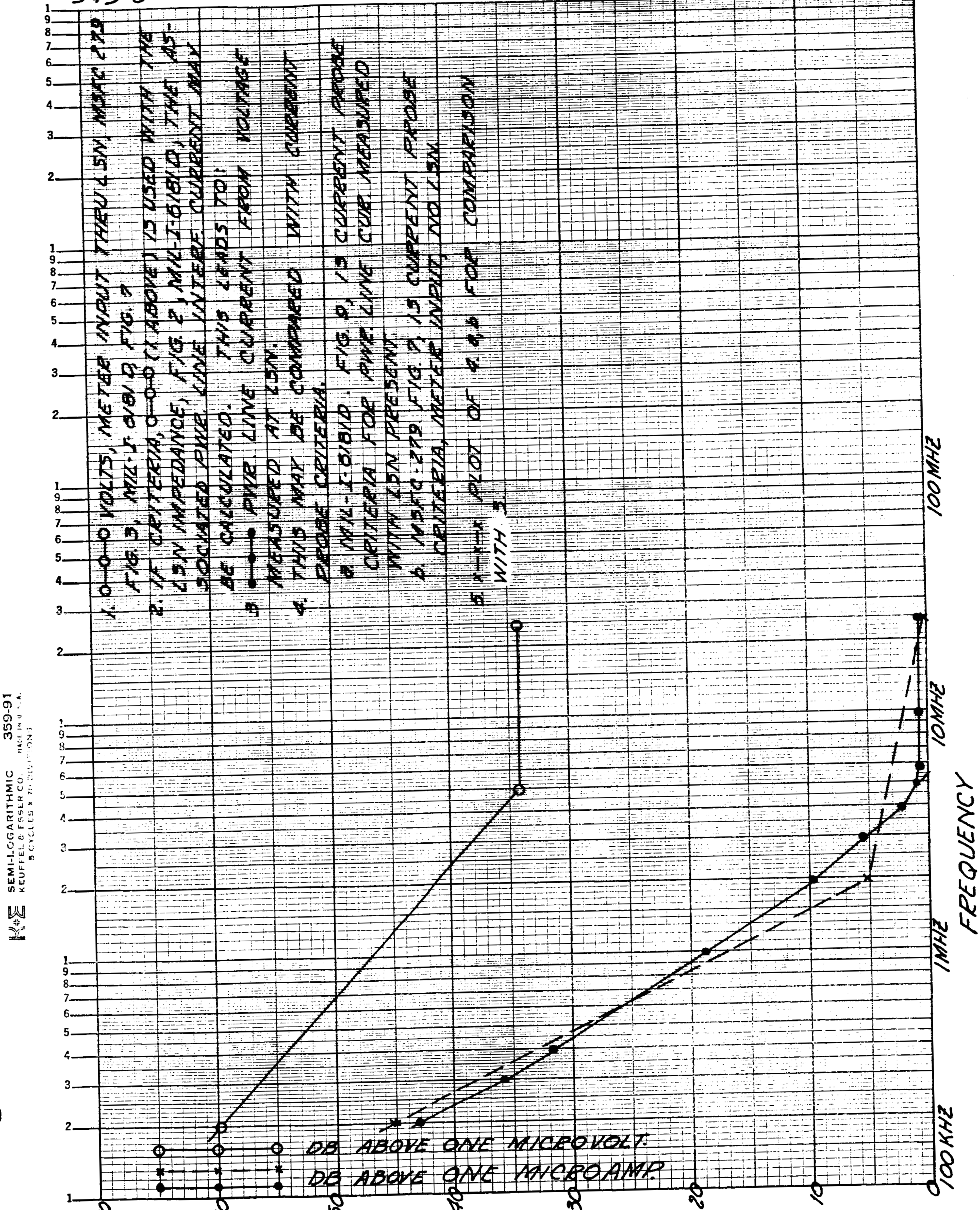

FIGURE 2. CW PWR LINE COND. INTERF. CRITERIA

2.1.2 Dependence of Interference Currents Upon Component Impedance. It was pointed out that in connection with the interpretation of Figure 1, impedances must be considered. Assumption of some reasonable impedances allows one to illustrate this point. It is sometimes assumed, quite mistakenly, that a battery power source such as used in space vehicles is such a low impedance by-pass to ground that there is no need to be concerned with interference superimposed onto DC power lines. The usefulness of this assumption depends upon the frequencies of concern and the relative impedances of the various components connected in the system. Figure 3 gives the results of some measurements of the Centaur vehicle battery impedance (GD/A Engineering Research Report, ERR-AN-433, 12-20-63).

It was observed that the impedance characteristic of Figure 3 is very similar to that of a typical lead-acid storage battery readily available for use in the laboratory to realistically simulate vehicle battery impedance.

Figure 4 is a block diagram of the essential elements of an audio susceptibility test of a package powered from the DC source. Test package impedances of 0.5 ohm (perhaps a DC to AC inverter) and 1000 ohms (perhaps a small transducer amplifier) were chosen to represent the extremes that may be encountered. The fact that there are numerous packages in parallel on the DC line and their input impedances are not all purely resistive or flat over the frequency range as considered herein should not make the conclusion arrived at invalid. Table I gives the impedances used and a tabular solution to the equations accompanying Figure 4. It should be noted that whereas MIL-I-6181D is explicit in stating the audio susceptibility requirement as being 3 V RMS across the open circuit secondary of the injection transformer, it is not clear if this is true for MSFC 279. It is assumed herein that MSFC 279 calls for 3 V RMS measured across the test package terminals. Equations (1), (2), and (3) given in Figure 4 are solved in Table I using the battery impedance shown in Figure 3. Figure 5 consists of plots of the currents resulting from audio susceptibility testing and the CW conducted interference criteria, Figure 6 of MSFC Specification No. 279. It is very interesting to note that a good percentage of the components are allowed to create a more severe environment than they are expected to withstand!

This would appear to be a paradox in setting specification criteria. It is not intended to be an alarmist statement for one must consider further to know what this means in terms of applicability of specification criteria in establishing electromagnetic compatibility. This critical examination will continue as part of the Phase II portion of this study. One may immediately, however, upon reference to Figure 5, make a few observations or pose a few questions. Some of these are:

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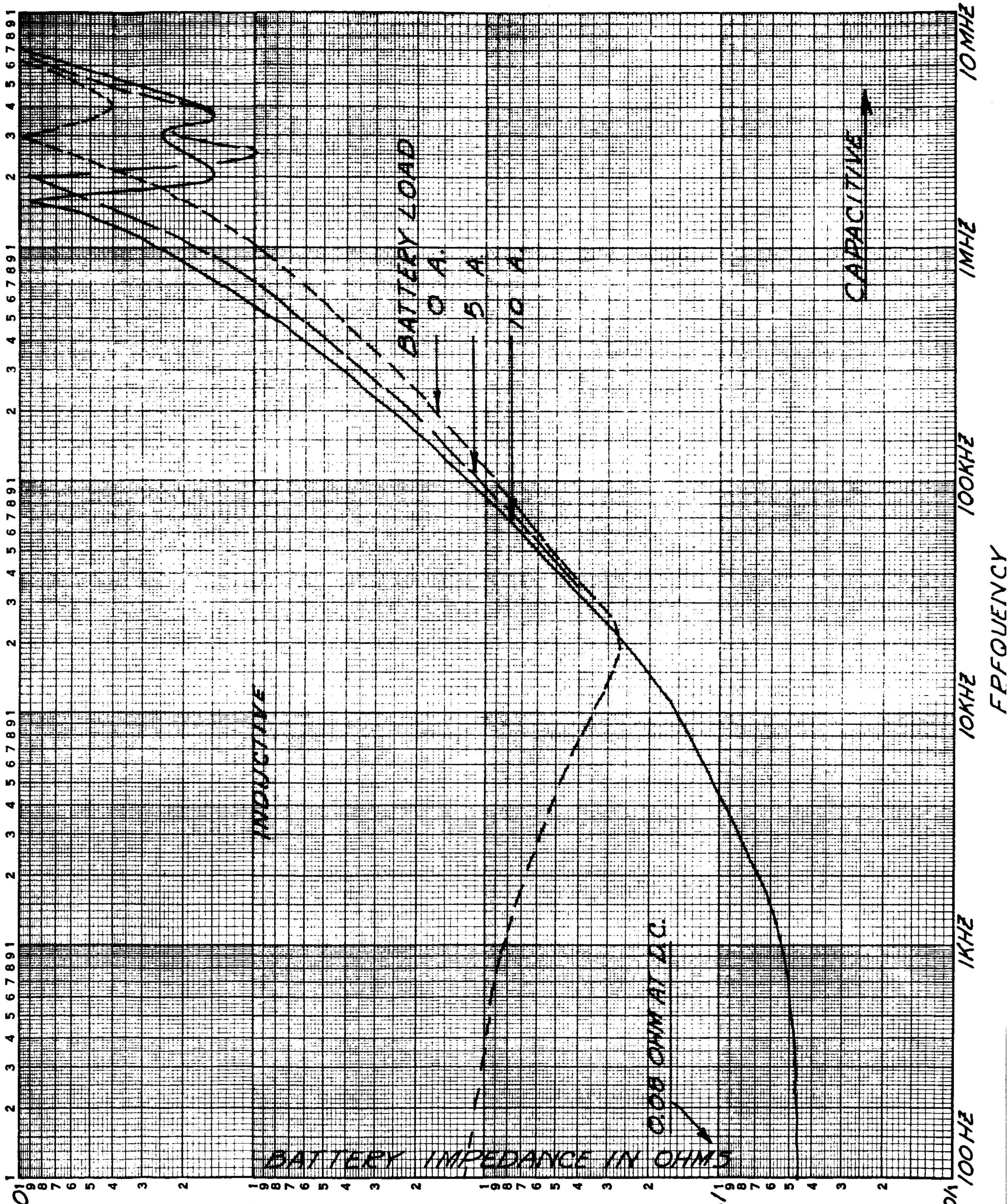
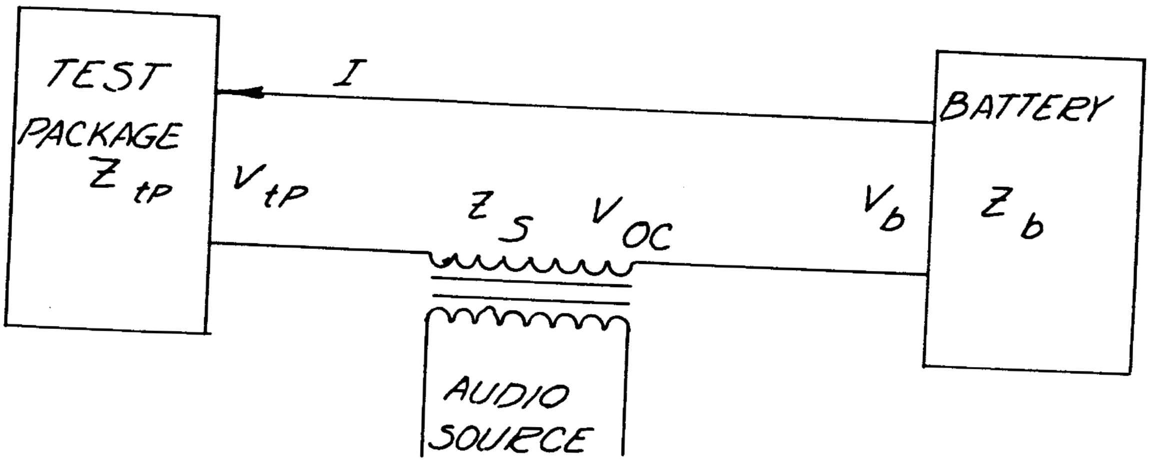


FIGURE 3 IMPEDANCE OF CENTAUR BATTERY



IN ACCORDANCE WITH MIL-I-6181D:

$Z_S \leq 0.6$ OHMS

$V_{OC} = 3$ V. RMS (WITH LOAD DISCONNECTED)

IT FOLLOWS THAT:

$$I = \frac{V_{OC}}{(Z_{tp} + Z_S + Z_b)} = \frac{3}{(Z_{tp} + 0.5 + Z_b)} \qquad (1)$$

(TAKING $Z_S = 0.5$ OHMS)

$$V_{tp} = \frac{Z_{tp}}{(Z_{tp} + Z_b)} \cdot V_{OC} = \frac{Z_{tp}}{(Z_{tp} + Z_b)} \cdot 3 \qquad (2)$$

IN ACCORDANCE WITH MSFC 279:

$Z_S = \leq 0.5$ OHMS

$V_{tp} = 10\%$ OF V_b

IT FOLLOWS THAT:

$$I = \frac{V_{tp}}{Z_{tp}} = \frac{3}{Z_{tp}} \quad \text{(USING 10\% OF } V_b = 3\text{)} \qquad (3)$$

FIGURE 4 AUDIO SUSCEPTIBILITY TEST

F	Z_b	Z_s	Z_{tp}	TOTAL Z	MIL-I-6181D V_{oc}	MIL-I-6181D I(A)	MIL-I-6181D I(DB MA)	MIL-I-6181D V_{tp}	MSFC 279 V_{tp}	MSFC 279 I(A)	MSFC 279 I(DB MA)
30 Hz	0.05	0.5	0.5	1.05	3	2.86	129.1	2.85	3	6.0	135.6
2.3KHz	0.08	0.5	0.5	1.08	3	2.78	128.8	2.78	3	6.0	135.6
15 KHz	0.2	0.5	0.5	1.20	3	2.50	128.0	2.15	3	6.0	135.6
30 KHz	0.35	0.5	0.5	1.35	3	2.22	126.9	1.76	3	6.0	135.6
50 KHz	0.6	0.5	0.5	1.60	3	1.88	125.5	1.36	3	6.0	135.6
100 KHz	1.0	0.5	0.5	2.00	3	1.50	123.5	1.00	3	6.0	135.6
150 KHz	1.2	0.5	0.5	2.20	3	1.36	122.7	0.88	3	6.0	135.6
30 Hz	0.05	0.5	1000	1000.55	3	0.003	69.5	3.00	3	0.003	69.5
2.3 KHz	0.08	0.5	1000	1000.58	3	0.003	69.5	3.00	3	0.003	69.5
15 KHz	0.2	0.5	1000	1000.7	3	0.003	69.5	3.00	3	0.003	69.5
30 KHz	0.35	0.5	1000	1000.85	3	0.003	69.5	3.00	3	0.003	69.5
50 KHz	0.6	0.5	1000	1001.1	3	0.003	69.5	3.00	3	0.003	69.5
100 KHz	1.0	0.5	1000	1001.5	3	0.003	69.5	2.99	3	0.003	69.5
150 KHz	1.2	0.5	1000	1001.7	3	0.003	69.5	2.99	3	0.003	69.5

Table I. SUSCEPTIBILITY CURRENTS AS A FUNCTION OF FREQUENCY AND IMPEDANCE.

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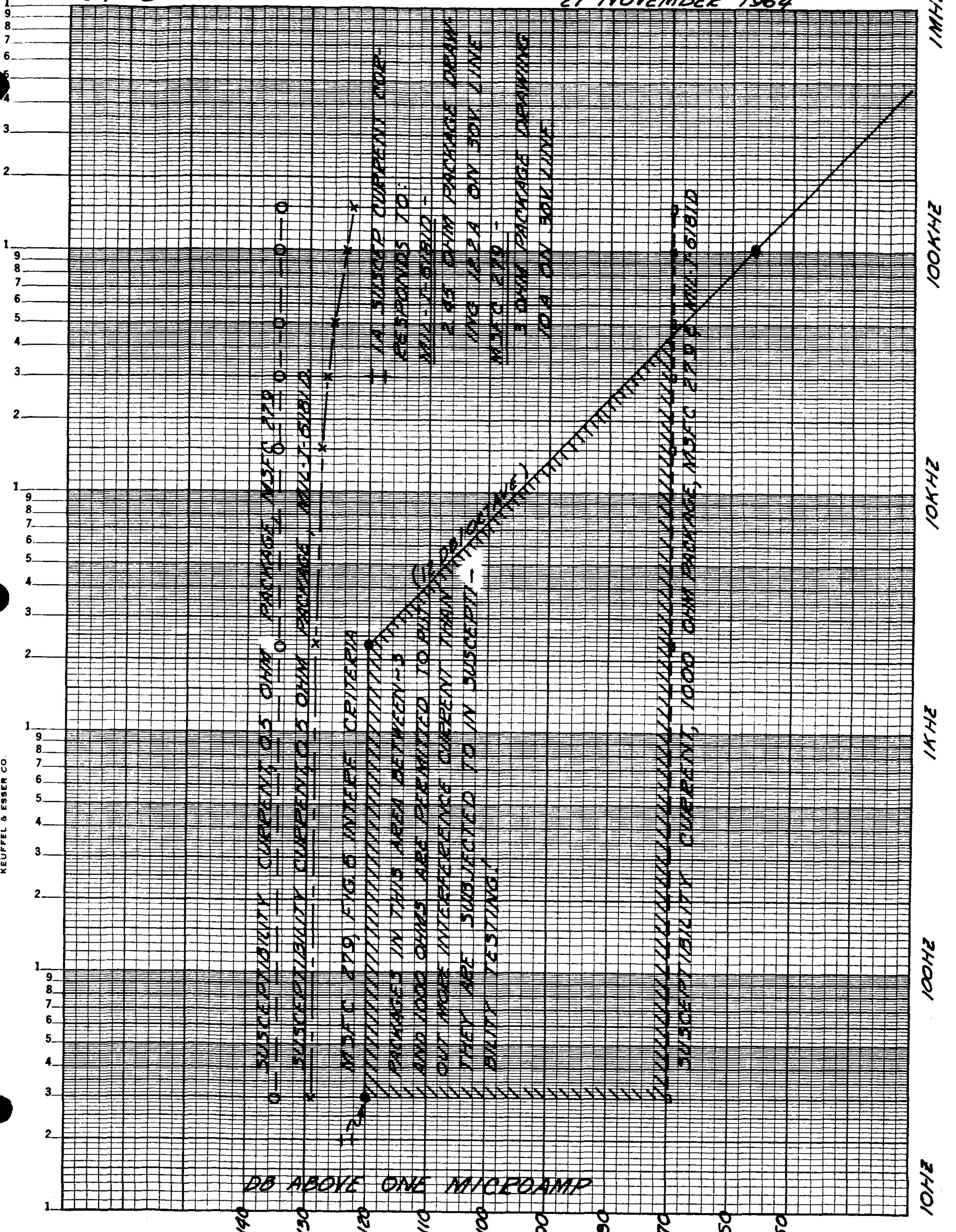


FIGURE 5. REALISTIC SUSCEPTIBILITY CURRENTS

a. Consider a 10 ohm package under test. In the susceptibility test this may experience about 0.3A of interference current which is less than the 1A interference current criteria. However, an interference generator within a package would have to sustain over 10 V to feed the 1A current limit onto the power line! Indeed, over 1 V would be required to exceed the 0.3A resulting from the susceptibility test! CW interference generators of this magnitude (at other than power frequencies) seem unlikely.

b. These considerations bring up questions of what is the nature of interference generators -- constant voltage or constant current?

c. One should also consider that many components either through normal design or through attempts at interference filtering may have capacitive power line inputs. Capacitance in the range of 0.1 to 1 mfd over the frequency range of 30 Hz to 2.3 KHz would result in impedances varying from 53 Kohms to 70 ohms. These often would exceed the resistive load of the package.

As previously mentioned, this type of analysis will continue as part of the process of learning how to effect a transition from existing practices to practices more directly useful within the intent of this contract study.

2.2 CONSIDERATIONS OF COMPONENT AND SYSTEMS LEVEL TESTING. In order to consider EMC checkout of large space vehicles in the same vein as functional automated checkout, the parameters to be measured and specifications have to be in a form compatible with automated checkout procedures and methods. Since component EMC specifications bear very little resemblance to systems EMC specifications it would seem logical that the first order of business would be to make component and systems EMC specifications as close to identical as possible for both levels of testing so that information gathered on the component level will be directly usable on the systems level. The present component specifications are in a form that would make it impossible to visualize any method of measurement other than the swept receiver approach and this approach is incompatible with the automated concept of systems checkout. Because of this incompatibility a major portion of this study will be directed toward reviewing present specifications and limits in the light of systems EMC measurement requirements. Since the present systems requirements dictate susceptibility as a criterion for systems measurements some of the areas covered in this study phase have been aimed at drawing together susceptibility testing and EMI measurements and procedure into test procedures that can gather data on the component level needed on the systems level.

In viewing EMC testing from the component and subsystem level one thing does become immediately apparent. Many tests are performed which do not produce information that can be used in system levels EMC evaluations. On the component level several test procedures are followed to obtain data on both the conducted and radiated environment. This data is obtained by the use of tuned receivers which scan the spectrum dictated by the specification in use. As was previously stated, the gathering of this data is necessitated by the fact that EMC is not considered in the design stage and the only route left to ensure electromagnetic compatibility is to test and suppress to some arbitrary limits. As previously noted some of these limits date back to the days of propeller driven aircraft and have not changed appreciably since that time. After the components and subsystems are integrated into the total system, it is desired to perform a systems EMC evaluation. At this time it becomes apparent that one of the only useful criteria in monitoring the total system is that of susceptibility. If concepts such as automatic checkout are considered for use in EMC evaluations, susceptibility of the components and subsystems becomes the only useful criteria for monitoring the total system. This is due to the fact that scanned spectrums can no longer be used on the systems level as a means of determining compatibility since this technique implies dwelling in time at a test point in the system while the spectrum is being scanned, an impossible technique to use when the total system is rapidly being checked out and various functions are being performed which could produce detrimental electromagnetic energy at various points in the spectrum at the same instant of time.

Experience has dictated that the approach to systems EMC evaluations be one of monitoring critical test points in a system, at levels determined by susceptibility tests, while the total system is being checked out. It is apparent that this type of evaluation requires only that accurate susceptibility data be taken on component and subsystem level tests.

2.2.1 CW Conducted Interference. The first area covered as an example of how a component level test could gather data necessary for the systems EMC evaluations in a form which can lend itself to the automated approach is that of conducted (CW) interference measurements in the 150 KHz to 25 MHz frequency range.

Figure 1 shows the specification limits for measurement of conducted interference on a power line using an LSN compared to the specification limit for susceptibility over the same frequency range. Two alternatives can be considered to make the component and systems test more nearly identical in nature.

a. Since the susceptibility test function is so much higher in amplitude than the allowed measured interference, all packages meeting this level of susceptibility at their 28V **or** 115V input could waive the interference criteria of Figure 1 (with due consideration given to impedances as discussed in Paragraph 2.1.2). If this were done, the test criterion used on the component test would serve as the monitoring criterion on the system level EMC test; i.e., the package would be subjected to Figure 1 on a component susceptibility test and this level or -6 db of this level could be monitored in the system test.

b. The component under test could be subjected to the arbitrary limits of Figure 1, and made to comply to these limits. In the system the power line inputs could then be monitored through inverse filters shaped to the specification limit to determine compliance in the system. This test would, however, be arbitrary since limits may be unrealistically low. This test would also be more difficult since detectors used in the system would need filters designed for their input.

All of the above comments assume that the LSN and measuring instrumentation would not load the line being measured which is usually not the case. A more valid test would involve monitoring the amplitude of the susceptibility test function present at the power line input with a non-disturbing probe. More can be said about this after considering current specification limits in the light of the discussion above. In the present current specification, shown in Figure 5, it is very hard to make any comparison bewteen susceptibility test functions used to test components and the allowable limits of measured interference. This is mainly due to the fact that susceptibility test functions are given in volts. Since the impedance at the power input to a package under test is not known as a function of frequency, a current susceptibility level cannot be established. If, however, the closed circuit voltage Vcc and the current i, Figure 6 are monitored, these are things that may be used in forming criteria for monitoring in the system.

There are two possible solutions to the systems compatibility problem. (1) Stop every component in the systems from putting out any interference above a certain level and (2) stop everything from being a receptor of interference above a certain level. Solution (1) is impractical because there are many operations within the system which will require that high levels of interference exist for short periods of time. Even turning a piece of equipment on during operations of a system can cause interference well in excess of specification limits.

Solution (2) is practical because a high level susceptibility test function can be chosen for all components and packages can be minimally filtered, if susceptible, to meet the requirements of the high test function used. In this way all packages will be known to be able to take at least the level of the test function used.

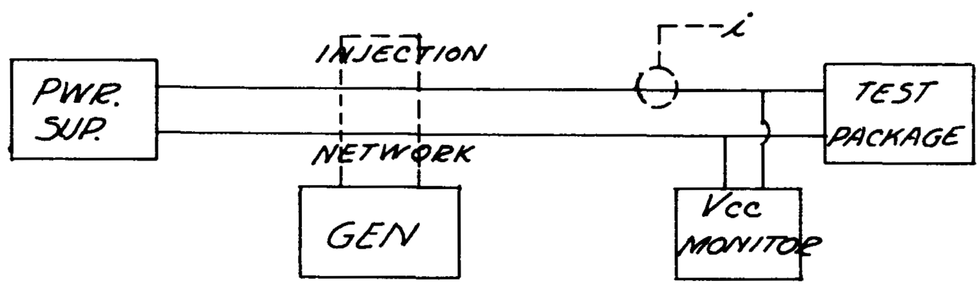


FIGURE 6 CW CURRENT PROBE TYPICAL TEST SETUP FOR SUSCEPTIBILITY

With this type of test it is not necessary that the susceptibility test function be high enough to produce a malfunction because if V_{CC} is monitored at the power line input to the package under test, it will be duly noted if the package under test produces any interference in excess of that susceptibility signal being put in. Therefore, in the frequency range of the susceptibility test two pieces of information will be gathered; (1) does a malfunction occur as a result of V_{CC} and (2) is the package under test producing any CW interference which exceeds that which is put in.

The answer to (2) will in most cases be, "NO". Therefore, assurance of compatibility can be made since each package in the system will be made to take the susceptibility test function and will be checked to make sure it produces no interference in excess of that susceptibility test function.

Since the susceptibility criterion in the MSFC Specification No. 279 recommends developing 1V RMS across 50 ohms as the susceptibility test function in the 150 Hz to 400 MHz frequency range, both a voltage and a current specification can be recommended which will serve as a component specification limit and monitoring level for a systems EMC evaluation.

Consider first, the voltage specification of the susceptibility test function as 1V RMS. As long as the input impedance of the package under test is 50 ohms or greater, 1V RMS can remain as the susceptibility test function and monitoring to within 6 db of this level on a system can take place with voltage probes and detectors. If Z drops below 50 ohms, the generator output would have to be increased to maintain 1 V RMS as V_{CC}. Since all generators used in susceptibility testing are limited in the range of output, there will have to be some practical limit to the increase in generator output to maintain V_{CC} at 1 V RMS while the input impedance of the package under test is decreasing below 50 ohms. For instance, if the generator used is capable of delivering 2 watts into a 50 ohm load it will deliver 0.4A into a short circuit (ignoring transmission line effects). This would mean that approximately 1 V RMS could be maintained acrosss an impedance of 2.5 ohms. If the impedance dropped below 2.5 ohms, 1 V RMS could no longer be maintained acrosss the load but the current of 0.4A could be monitored. If both current and voltage are monitored as shown in Figure 6, it would be possible to determine if it is more advantageous to monitor current or voltage within a system. If the voltage was lower than 1 V RMS, it is likely that the current would be high enough to be monitored. In this case the susceptibility level (in terms of current) can become the monitoring level within the system. The monitoring levels needed for a system EMC evaluation can thus be obtained in terms of voltage or current directly from component susceptibility tests and if the components are made to meet these levels and do not generate CW interference in excess of these levels, compatibility within the power distribution system should be assured.

2.2.2 CW Conducted Susceptibility. One of the areas with which this study is concerned is cutting down in duplication of testing and using procedures which make monitoring of interference levels on power lines at low frequencies on the component level more compatible with methods used in the systems level. One area that immediately suggests itself is the audio susceptibility test over the frequency range of 30 Hz to 150 KHz. It has been long realized that audio susceptibility tests and transient tests cover appreciably the same frequencies at the low end of the spectrum and that it may be very possible to uncover CW susceptibility and transient susceptibility with the same test procedure. If a pulse train were to be used as a first-go-around test it can be shown that the same amplitudes required on a CW test can be reached.

The spectrum of a square pulse can be shown to be:

$$F(\omega) = \frac{ET_1}{T} \frac{\sin \omega T_1/2}{\omega T_1/2}$$

This is seen to be a familiar sin x/x type frequency distribution with frequency components located at intervals of 1/T as shown in Figure 7. T_1 is chosen so that the spectrum is relatively flat over the range of CW audio susceptibility testing and 3 volts is chosen as the amplitude necessary on a 28 V power line. E can be determined for a given T.

Let $A = E \frac{T_1}{T}$ where: $A = 3$ V
$T_1 = 0.067\text{x}10^{-3}$ sec.
$T = 10^{-3}$ sec.

Then $E = \frac{3(1\text{x}10^{-3})}{0.067\text{x}10^{-3}} = 45$ V.

Therefore if a 45 volt square pulse with a duration of 67 μ sec and a period of 1 Msec. were used, the frequency spectrum would consist of frequency components 1 KHz apart of sufficient amplitude to meet most of the requirements of the CW audio susceptibility test up to 15 Kc. In fact, if the nulls in the spectrum could be tolerated, this could be a usable test up to much higher frequencies. The amplitude of 45 V is not especially high in light of present transient tests which use a 50 volt test function. The 1 KHz spread in frequency components may cause some concern because this leaves some extensive holes in the audio spectrum. However, since the 3 db bandwidth of the test sample (at the power input terminals) can usually be considered to be quite a bit greater than 1 KHz, more than the 3 volt peak signal would be injected into the test sample terminals. For example, if the bandwidth were 3 KHz nearly 9 volts would be injected into the test sample terminals.

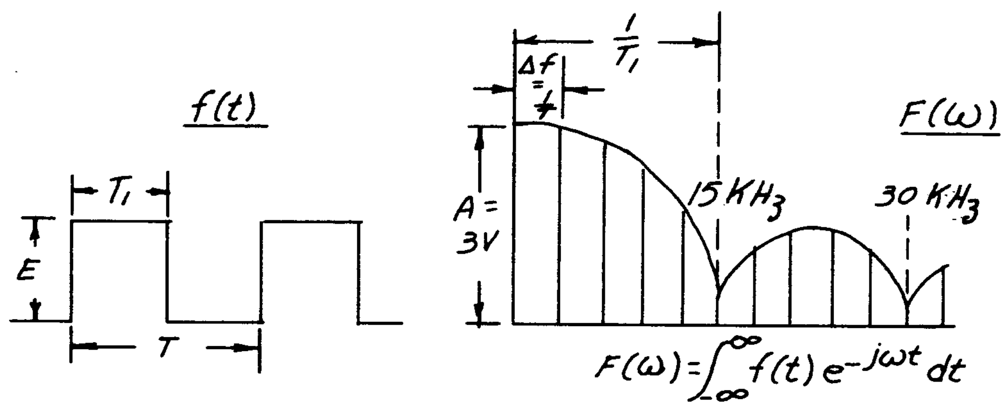


FIGURE 7 SPECTRUM ASSOCIATED WITH A SQUARE PULSE TRAIN OF DURATION T_1 AND PRF = $\frac{1}{T}$

If a susceptibility were discovered using this test technique determination of whether the susceptibility were just a transient amplitude susceptibility (broadband case) or a CW susceptibility (narrow band case) could be made by varying the prf of the pulse train. For example, if the susceptibility bandwidth were 1 KHz and the following conditions were true -

OPERATION: prf increased from 1 KHz to 2 KHz.

RESULT: Susceptibility present at 1 KHz prf disappears.

CONCLUSION: The susceptibility of the test sample was probably to a CW signal.

If the following conditions were true -

OPERATION: Decrease prf from 1 KHz to 500 Hz.

RESULT: Susceptibility at 1 KHz prf remained.

CONCLUSION: The susceptibility of the test sample would be primarily broadband and associated with the transient amplitude.

This type of test would be useful in cutting down component test time and the equipment needed in performing tests. Levels of susceptibility could also be established that would be directly usable in a systems EMC evaluation.

2.3 CONFLICT BETWEEN INTERFERENCE CRITERIA AND SYSTEMS REQUIREMENTS.

2.3.1 On Establishing Specification Limits Based on Functional Requirements. Broadband Conducted (An Approach). Present limits imposed on components are a result of arbitrary choice, but also involve the extent to which EMC is considered in the initial design of the component. If EMC has not been one of the prime design considerations, the finished product can only be tested to arbitrary specification limits due to the fact that functions performed within the system are only known from an operational viewpoint. For instance, if a chopper power supply is designed for the purpose of delivering AC or DC power to other components within a system without paying heed to the type of impulse interference it produces on a 28V power line and the susceptibilities of other components that may share the same 28V power, then this unit can only be tested to an arbitrary specification limit and suppressed in accordance with this arbitrary limit. This is the most common practice used in EMC testing to date.

Since EMC testing is not confined to power lines, but also includes signal lines, it is not reasonable to assume that the limits for all channels (here channels refers to information lines, power lines, etc.) can be the same. These limits in the practical case have to be based on the susceptibility of any black box tied into a specified channel. In the case of power lines, this viewpoint becomes very difficult to handle due to the fact that many components share the same power supply in an actual system and the channel impedance is modified each time a new component is added to the channel (since all components tied to a power line can be considered to be parallel). Difficulties also arise due to the fact that coupling factors between packages are not clearly defined because of arbitrary cable runs made in harness assemblies which are not controlled from an EMC viewpoint. Because of these difficulties it would be expedient to consider a specification limit for power lines which would reflect the consideration of the most susceptible item tied to the power supply. It has been previously noted that one trap that should not be fallen into is to assume that the power supply (often a 28V battery) is a low impedance and therefore acts as a short or sump for interference generated by a package tied to it. That battery can represent a sizable impedance at RF frequencies, therefore interference generated at one point in a system can easily be transmitted past the battery to any other point in the system purely via conducted paths.

EMC considerations in information channels, however, can be handled much more simply than in power lines due to the fact that in most cases only a transmitting and receiving system is considered to be tied together via the information channel. If consideration now is directed toward broadband conducted interference, some primary assumptions can be made in setting up limits based on system operational requirements and a knowledge of the various types of broadband conducted interference which can be present in the system. This type of interference for the most part is caused by various switching requirements in the system. Figure 8 shows a group of waveforms which could represent most switching operations in a system and the frequency spectra associated with them. Waveforms (a), (c), (d), show a 6 db/octave roll-off with frequency, but this requires that the waveforms have a zero rise time. In the practical case the rise times will be modified as in (b) and (e) and it is seen that the spectrum is then modified to have a 12 db per octave roll-off with frequency.

Since the switching phenomenon produces these transient waveshapes, a note should be injected to point out why it is very difficult to meet present specification limits in circuits where this type of phenomenon takes place. Most limits seen in present specifications do not exhibit a 12 db/octave roll-off with frequency and are arbitrarily terminated at some low frequency f_1 as shown in Figure 9. Below f_1 the specification is made arbitrarily flat. This arbitrary termination to a flat specification limit below f_1 plus the arbitrary roll-off with frequency is what makes it so difficult for a component producing transients to meet the broadband specification limits. This can be shown in an example

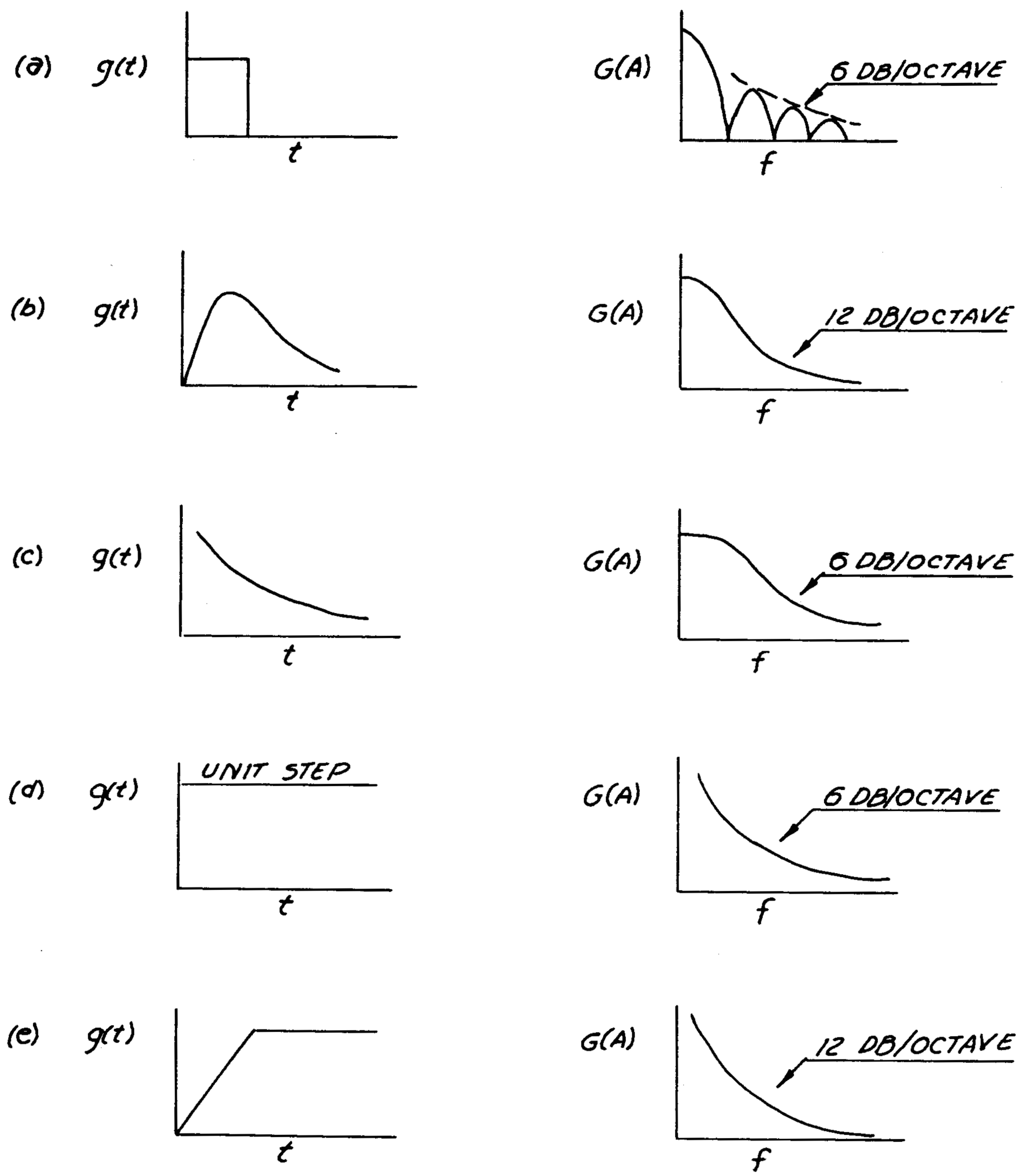


FIG. 8 SOURCES OF BROADBAND EMI WITHIN A SYSTEM

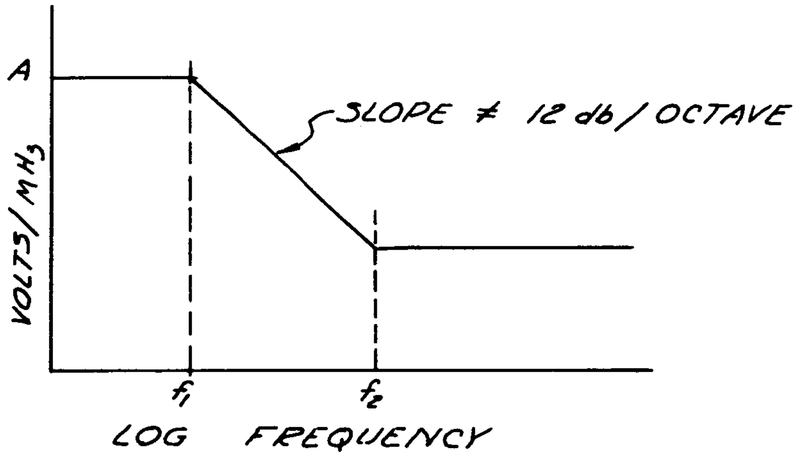


FIGURE 9 TYPICAL INTERFERENCE CRITERIA SHAPE

$K = \text{SLOPE} = \frac{30V}{0.1 \times 10^{-6} \text{SEC.}} = 300 \times 10^{6} \frac{V}{\text{SEC.}}$

$F(\omega) = \frac{K}{S^2}$ WHERE $S = j\omega$

FIGURE 10 TIME AND FREQUENCY DOMAINS OF TYPICAL SWITCHING OPERATION considering a device which is merely turned on such as a component which is switched on to a 30 volt battery. In this example it can be assumed that the load is purely resistive.

As can be seen in Figure 10(a), the waveform at the component will rise to 30 V in some finite period of time (0.1 μ sec is chosen for this example). The spectrum generated by this waveshape is shown in Figure 10(b) and is arrived at by using the Fourier analysis of the waveform f(t). $F(\omega)$ is given in Figure 10(b). Since the spectrum falls off at a rate of $1/f^2$, it is convenient to reference all values of $F(\omega)$ to 1 Hz.

a. 1 Hz, $F(\omega) = \frac{K}{S^2} = \frac{300 \times 10^6 \text{ V/sec}}{(2\pi)^2 (\text{Hz})^2} = \frac{300 \times 10^6 \text{ V Hz}}{(2\pi)^2 (\text{Hz})^2}$

$$= \frac{300 \times 10^6 \text{ V}}{(2\pi)^2 \text{ Hz}} = \frac{300 \times 10^{12} \text{ V}}{(2\pi)^2 \text{ MHz}} = 7.6 \times 10^{12} \frac{\text{V}}{\text{MHz}} = 378 \text{ DB above } \frac{1 \mu\text{V}}{\text{MHz}}$$

At any other frequency $F(\omega)$ @ 1 Hz can be devided by $1/f^2$ to obtain the theoretical value of $F(\omega)$ at that frequency.

For example:

b. 20Hz, $F(\omega) = \frac{7.6 \times 10^{12} \text{ V/MHz}}{(20)^2} = 0.019 \times 10^{12} \frac{\text{V}}{\text{MHz}} - 326 \text{ DB above } 1 \frac{\mu\text{V}}{\text{Mhz}}$

c. 15KHz, $F(\omega) = \frac{7.6 \times 10^{12} \text{ V/MHz}}{(15 \times 10^3)^2} = 0.0338 \times 10^6 \frac{\text{V}}{\text{MHz}} = 210 \text{ DB above } 1 \frac{\mu\text{V}}{\text{MHz}}$

d. 100KHz, $F(\omega) = \frac{7.6 \times 10^{12} \text{ V/MHz}}{(0.1 \times 10^6)^2} = 760 \frac{\text{V}}{\text{MHz}} = 178 \text{ DB above } 1 \frac{\mu\text{V}}{\text{MHz}}$

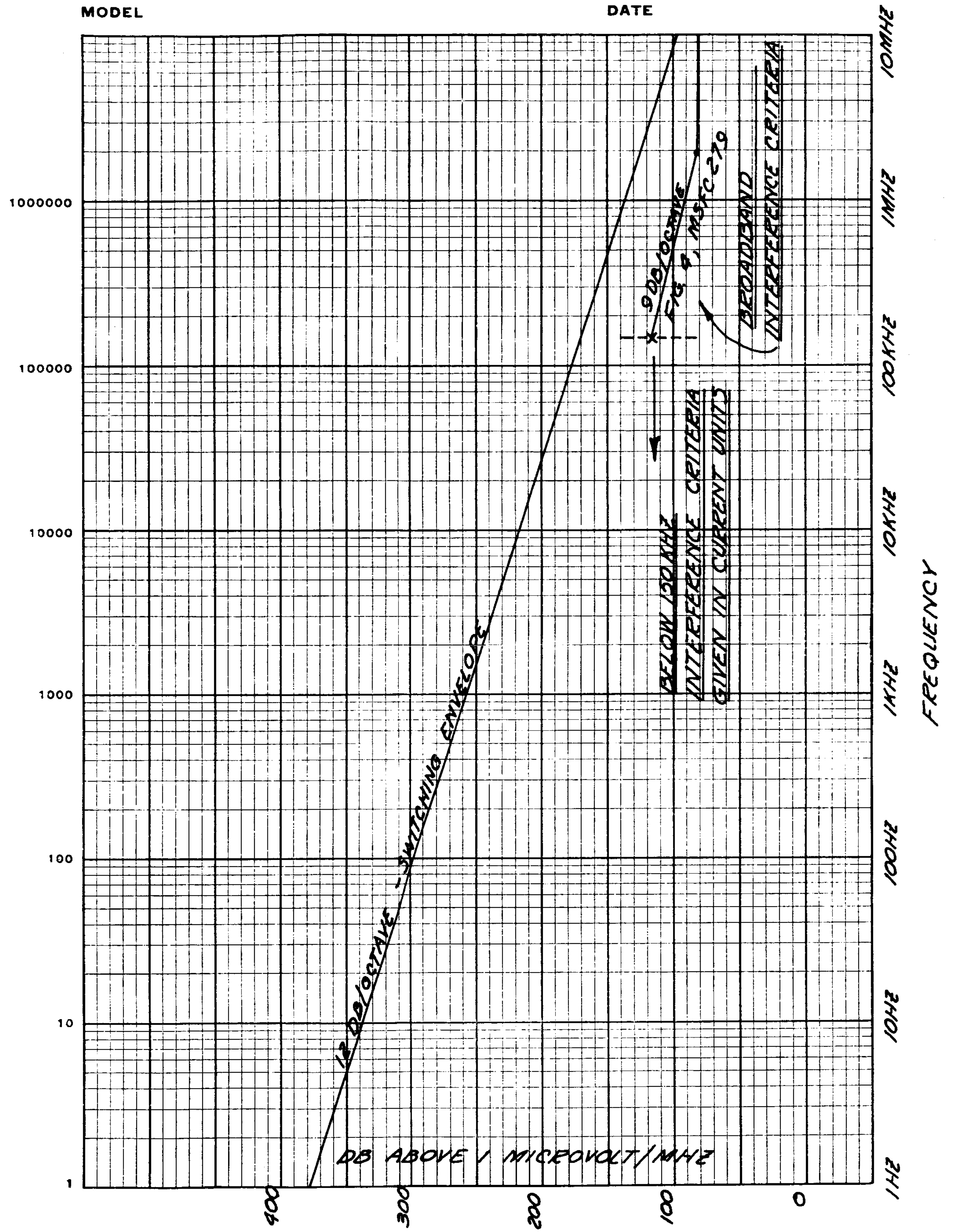
c. 1MHz, $F(\omega) = \frac{7.6 \times 10^{12} \text{ V/MHz}}{(10^6)^2} = 7.6 \frac{\text{V}}{\text{MHz}} = 138 \text{ DB above } 1 \frac{\mu\text{V}}{\text{MHz}}$

f. 10MHz, $F(\omega) = \frac{7.6 \times 10^{12} \text{ V/MHz}}{(10^7)^2} = 0.076 \frac{\text{V}}{\text{MHz}} = 98 \text{ DB above } 1 \frac{\mu\text{V}}{\text{MHz}}$

g. 25MHz, $F(\omega) = \frac{7.6 \times 10^{12} \text{ V/MHz}}{(25 \times 10^6)^2} = 0.01215 \frac{\text{V}}{\text{MHz}} = 82 \text{ DB Above } 1 \frac{\mu\text{V}}{\text{MHz}}$

As can be seen from the above data, $F(\omega)$ is quite a bit higher than any of the recent specification limits. Figure 11 shows this. It can also be concluded that it is not feasible to include transients of this type in the category of broadband interference due to the fact that it could not by it's very nature meet such specification limits. If the operational restrictions included that the rise time (or turn on time) had to be 0.1 μsec., as cited in the above example, there could be no suppression possible that would help this situation since suppression in effect could only increase the rise time. The rise time in this particular example would have to be increased several orders of magnitude before any appreciable improvement would be noted. In effect, what is being said here is that the only way this particular component could meet present specification limits is to never turn it on. If the present trend in specification limits continues to lower frequencies such as 20 Hz, serious consideration will have to be given to the types of interference which will be exempted or specifications will have to more and more reflect systems operational requirements.

2.3.2 Consideration of the transient problem. Since one of the main susceptibilities in large systems is to transients, the transient susceptibility test becomes a very important part of the component and subsystem level tests. One of the persistent problems encountered in EMC transient testing, however, revolves around how data is gathered on the component and subsystem level and the systems level. This is shown in Figure 12. Component B is found to be susceptible to transients of a certain time duration and amplitude (may also be susceptible to only amplitude). Component A is found to put out transients, but these transients are measured by standard band limited receivers according to some amplitude-frequency specification limit in a component type test. These two pieces of information cannot be put together to find if A will interfere with B because of the manner in which the data on A is taken. It turns out that the frequency domain is inadequate to describe the transient from A in terms of the susceptibility data taken on B. This can be explained by refering to Figure 13. Figure 13 shows four (4) different square pulses and the spectra of these pulses. The four pulses examined are (a) d = 1 μsec. A = 1 volt (b) d = 10 μsec. A = 1 volt (c) d = 0.1 μsec. A = 10 volt (d) d = 1 μsec. A = 10 volts. Using (a) as a standard of comparison it can be seen that (b) has a higher amplitude-frequency spectrum up to 320 KHz and then has an identical spectrum envelope as (a) above 320 KHz. (c) is seen to have the same amplitude-frequency spectrum as (a) below 320 KHz and a higher spectrum envelope amplitude above 320 KHz. (d) is seen to be the only case where the spectrum is higher than (a) throughout the entire frequency range shown. The important things to note is that (b) and (c) do have frequency plots identical to (a) over certain portions of the frequency range. Because of this it is impossible to interpret transient data measured on component and subsystems test in terms of information needed to determine EMC on the systems level. If the data taken were in the time domain, determination of how component A, Figure 12 would effect component B could be made.



K&E SEMI-LOGARITHMIC 359-96
KEUFFEL & ESSER CO. MADE IN U.S.A.
7 CYCLES X 60 DIVISIONS

FIGURE 11. GRAPH OF TYPICAL SWITCHING SPECTRUM

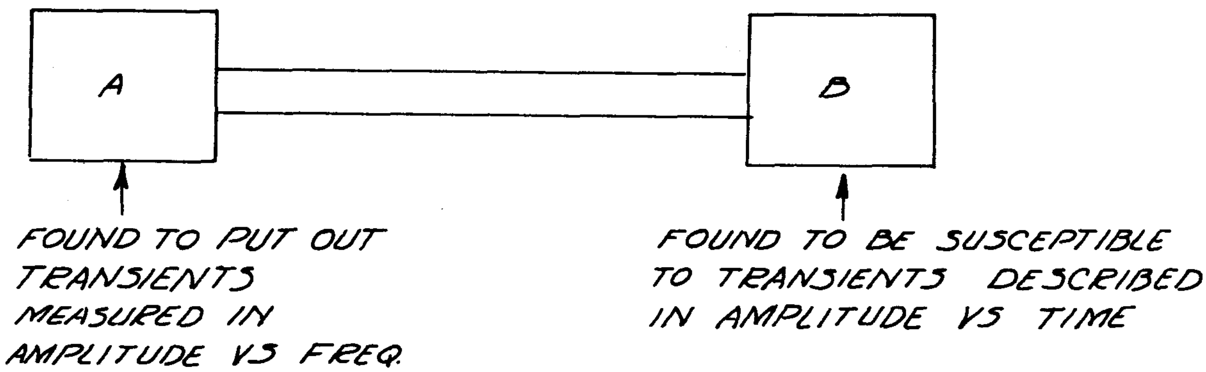


FIGURE 12 SUSCEPTIBILITY CONCEPT SETUP

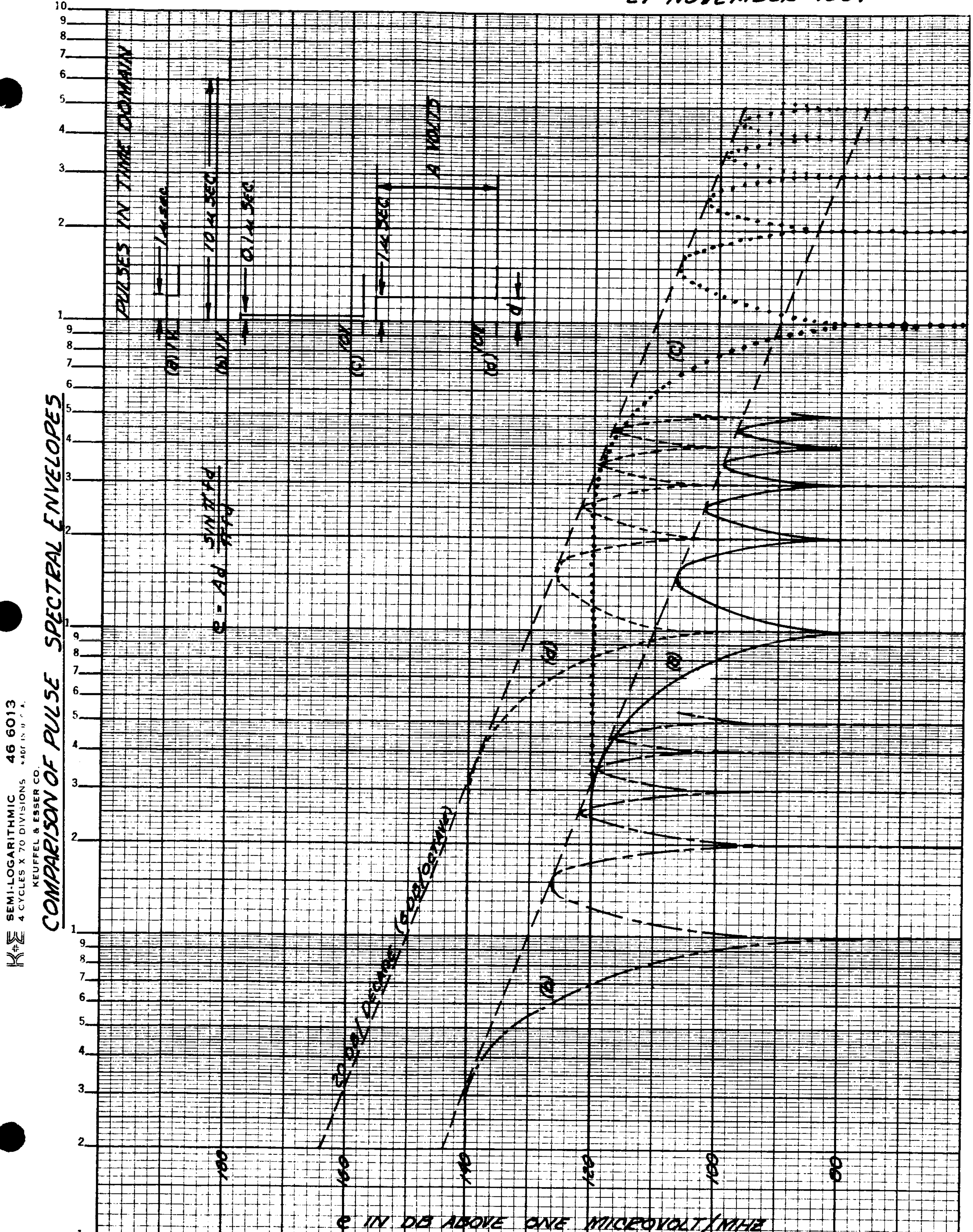


FIGURE 13 COMPARISON OF PULSE SPECTRAL ENVELOPES

An example of this can be seen by considering B to be susceptible to transients of an amplitude of 5 volts and any duration (i.e., amplitude susceptible). Referring to the time domain plots of the pulses of Figure 13, it is apparent that (a) and (b) would not cause any problems, but (c) and (d) would. (a) and (c) have similar spectrums and (b) and (d) have similar spectrums over parts of the frequency domain as stated previously. Therefore (b) and (d) may be considered to constitute detrimental interference on the basis of a frequency domain analysis. It can be noted here that none of the above statements hold true for sine wave susceptibility. If a component is found to be sine wave susceptible, frequency domain analysis is clearly defined and band limited instruments do not shade the data taken so that EMC can be determined on the systems level with data taken on component and subsystem tests.

It may be found during the course of transient susceptibility analysis that duration, amplitude and rise time are all important parameters to consider. Once again it will be more useful for systems evaluations if data taken on component and subsystem tests are in the time domain since all the statements made above regarding the square pulse and its frequency domain representation still hold true with the exception of modifications at higher frequencies due to pulse rise time. Figure 14 shows the frequency spectrum of a trapezoidal pulse with various rise times. As can be seen, the rise time causes the spectrum envelope drop off rate to double at a frequency dictated by the rise time of the pulse $f = 1/\pi t_r$.

In the frequency domain this effect of rise time is again not definitive enough in evaluating the EMC problem in the system. It is well known that solid state devices such as SCR's exhibit both rise time and amplitude susceptibility. Therefore a clear definition of this susceptibility in the time domain is necessary for any EMC evaluation.

One of the major areas of consideration over the coming months in this study will be susceptibility and how limits imposed on components and subsystems can also be tied to the system EMC evaluation under an automated checkout philosophy.

2.4 POSSIBLE REDUNDANCY IN TESTING.

2.4.1 RF Susceptibility Testing, Conducted and Radiated.

a. <u>Introduction to Experiment</u>. Since the input power line to a package under test can be compared to a Beverage type antenna, it was postulated that the RF conducted susceptibility testing may subject the package under test to as much radiation as a radiated susceptibility test. This theory was based upon the

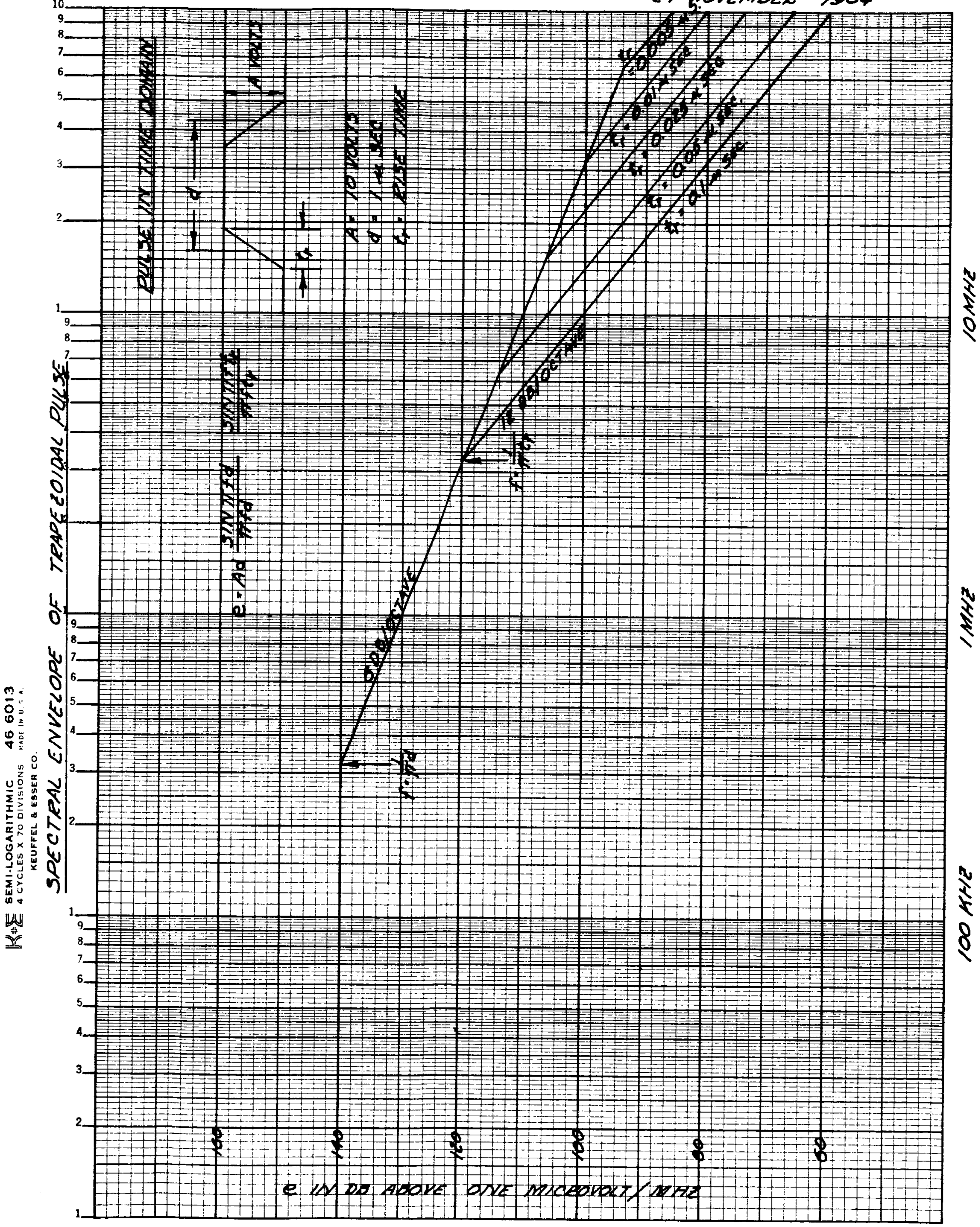


FIGURE 14 SPECTRAL ENVELOPE OF TRAPEZOIDAL PULSE

premise that the Beverage antenna radiates in the TEM mode when terminated in its characteristic impedance and input power line should radiate in this mode plus possibly others dependent upon the basic impedance mismatches and line losses. This proposition is somewhat substantiated by the fact that a review of several dozen EMC reports written over the last two years did not reveal any case where a component exhibited susceptibility responses to an RF field developed by driving an antenna with 100,000 microvolts or to 100,000 microvolts conducted directly onto the input power line. In fact, the case where a package exhibits susceptibility to the radiated RF field developed by 100,000 microvolts driving a 50 ohm antenna is very rare.

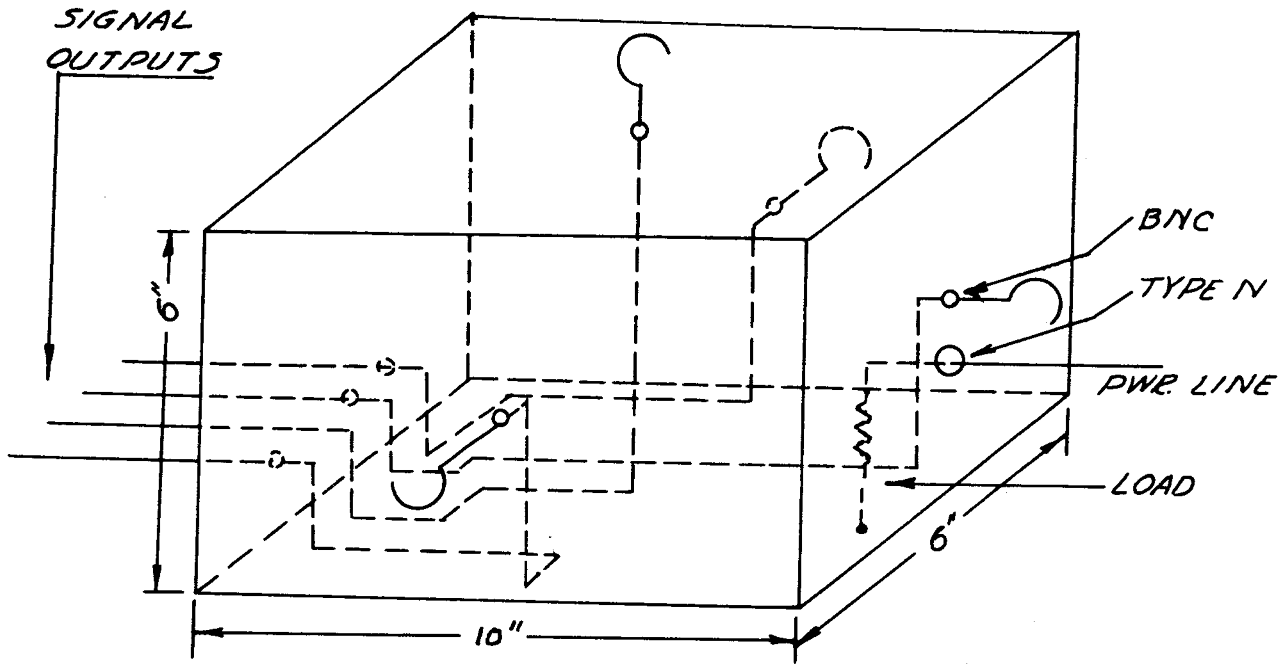
On the basis of the proposition that if RF conducted susceptibility testing might subject a package under test to comparable radiated energy as does the radiated susceptibility test, it may be that the low powered RF radiated test is redundant and may be discontinued.

The low powered radiated test offers little if any thing in the way of information usable in a systems EMC evaluation. If a susceptibility is uncovered with this test, it is very difficult to determine what the threshold of the susceptibility is in any measureable quantity. i.e., if a susceptibility is uncovered on a component test, what in the system could be measured to indicate the threshold of this susceptibility and where and how would this threshold be monitored? If the conducted RF susceptibility test reveals a susceptibility, whether this is produced by radiation from the line or the conducted energy on the line, the voltage across the package input terminals which produced this susceptibility can be monitored on both component and systems level.

The following is a report of an empirical comparison of measured radiated energy developed at the test package under both the conducted and radiated RF susceptibility tests.

b. Test Conditions. A copper box with approximate dimensions 10" x 6" x 6" was constructed. The line simulating the power line was brought into the box through a type N bulkhead mounted connector at the front and terminated to ground internally through various values of impedance. Pickup devices (probes) were attached to the sides, front, and top of the box and routed out the rear through BNC connectors. Figure 15 shows the above described test box and probes.

The test setup was as shown in Figure 16.



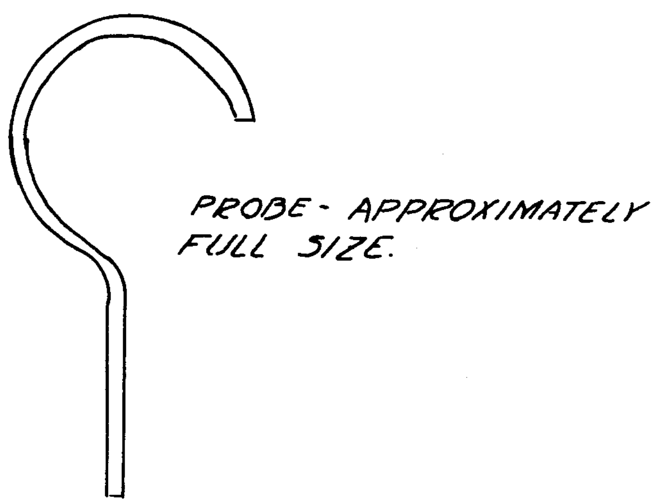


FIGURE 15 R.F. SUSCEPTIBILITY TEST
FIXTURE

CONTRACT NO. NAS 8-11426
27 NOVEMBER 1964

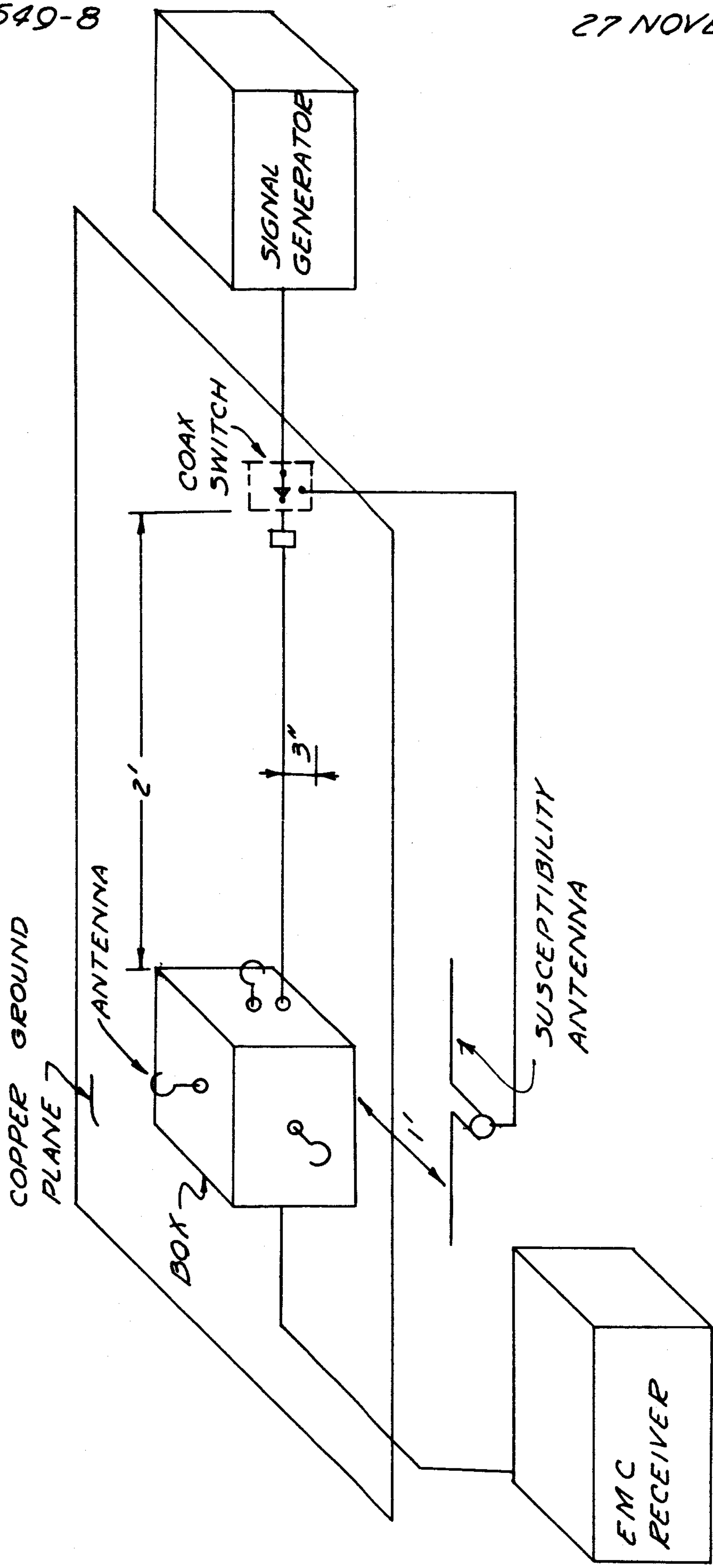


FIGURE 16 BASIC TEST SETUP

The input line was unterminated at the battery end during radiated testing since early in the evaluation it was determined that the load here had negligible effect on the results obtained. This is described in a later paragraph.

Figure 17 gives the setup used for determining the effect of loading at the battery end of the input line.

In all of the configurations mentioned above, the signal generator was set for maximum output.

c. Test Results. As is shown in the graphs (Figure 18 through 21), the pickup is comparable for both antenna radiation and line radiation on the test probes positioned on the sides and top of the test box for frequencies in excess of approximately 60 MHz. For the case where the pickup probe is positioned on the face of the box where the input line connects, the pickup is approximately equivalent for antenna and line radiated from 0.15 to 5 MHz and greater for the line radiated condition by an average of 16 db (varying from 6 to 32 db) for frequencies above 5 MHz. This condition is significant since the majority of discontinuities through which radiation can enter a package are associated with the input plugs which usually are located on this side.

Another question that arose in the evaluation was the effect of power supply loading on the test function. To evaluate this the setup illustrated in Figure 17 was utilizied and the line was successively shorted, loaded to fifty ohms, and left unterminated at the end representing the power source. These impedances represented the extremes that one could encounter in practice. The pickup data at the front of the box is presented in the graph, Figure 22.

Since during these evaluations the signal generators were set for maximum output, the data should possibly be supplemented by further evaluations where the voltage across the package terminals and the voltage across the antenna terminals are kept constant. During the evaluation reported herein, the voltage across the package terminals was less than across the antenna terminals for impedances less than 50 ohms and greater for impedances greater than 50 ohms. However, the voltage differences should be no greater than 6 db. The 50 ohm case should be directly comparable since both loads are now matched to the generator and equivalent amplitudes should be realized.

d. Conclusions. The data obtained during this evaluation substantiates the theory that line radiation presents comparable radiated energy at the package as antenna

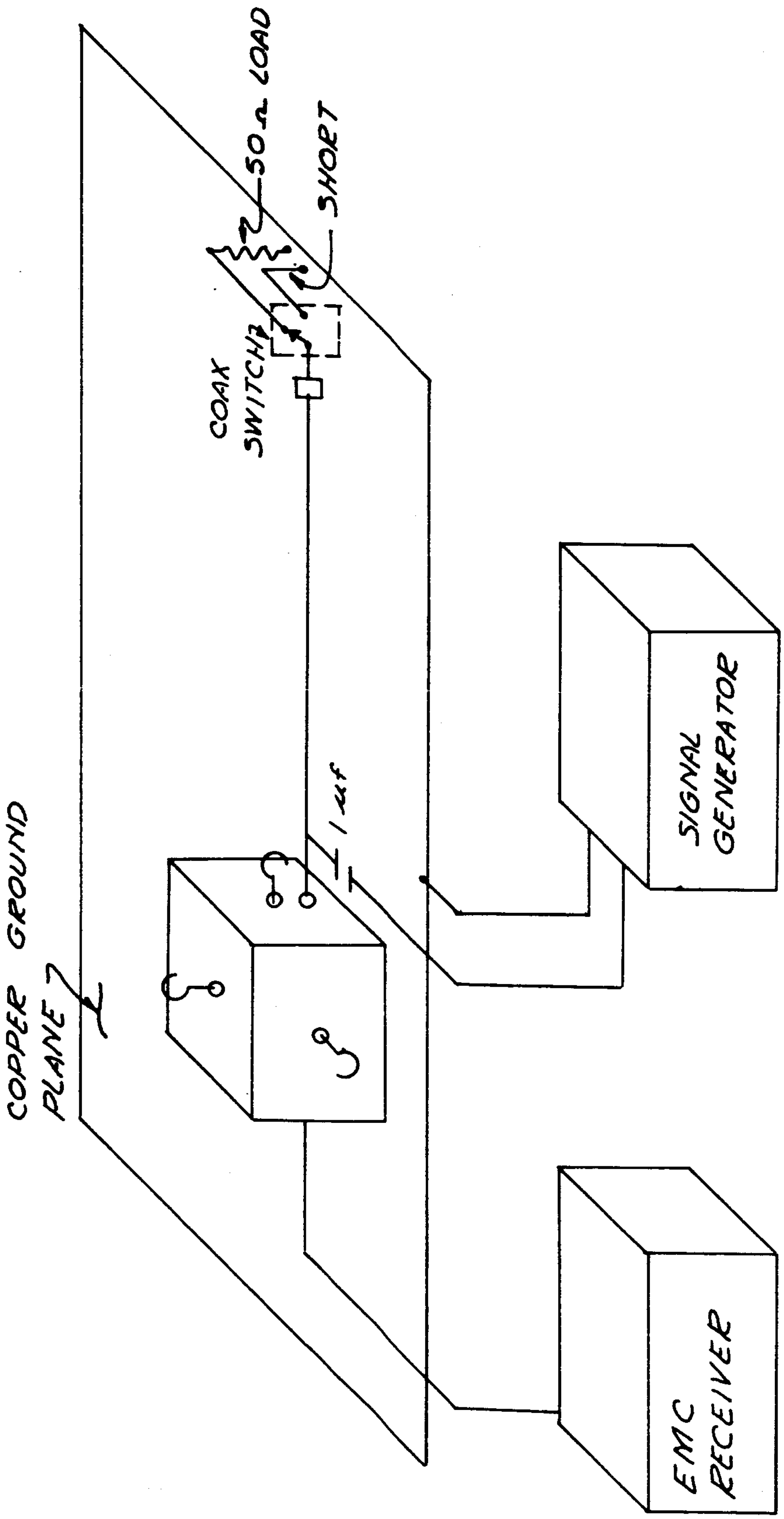
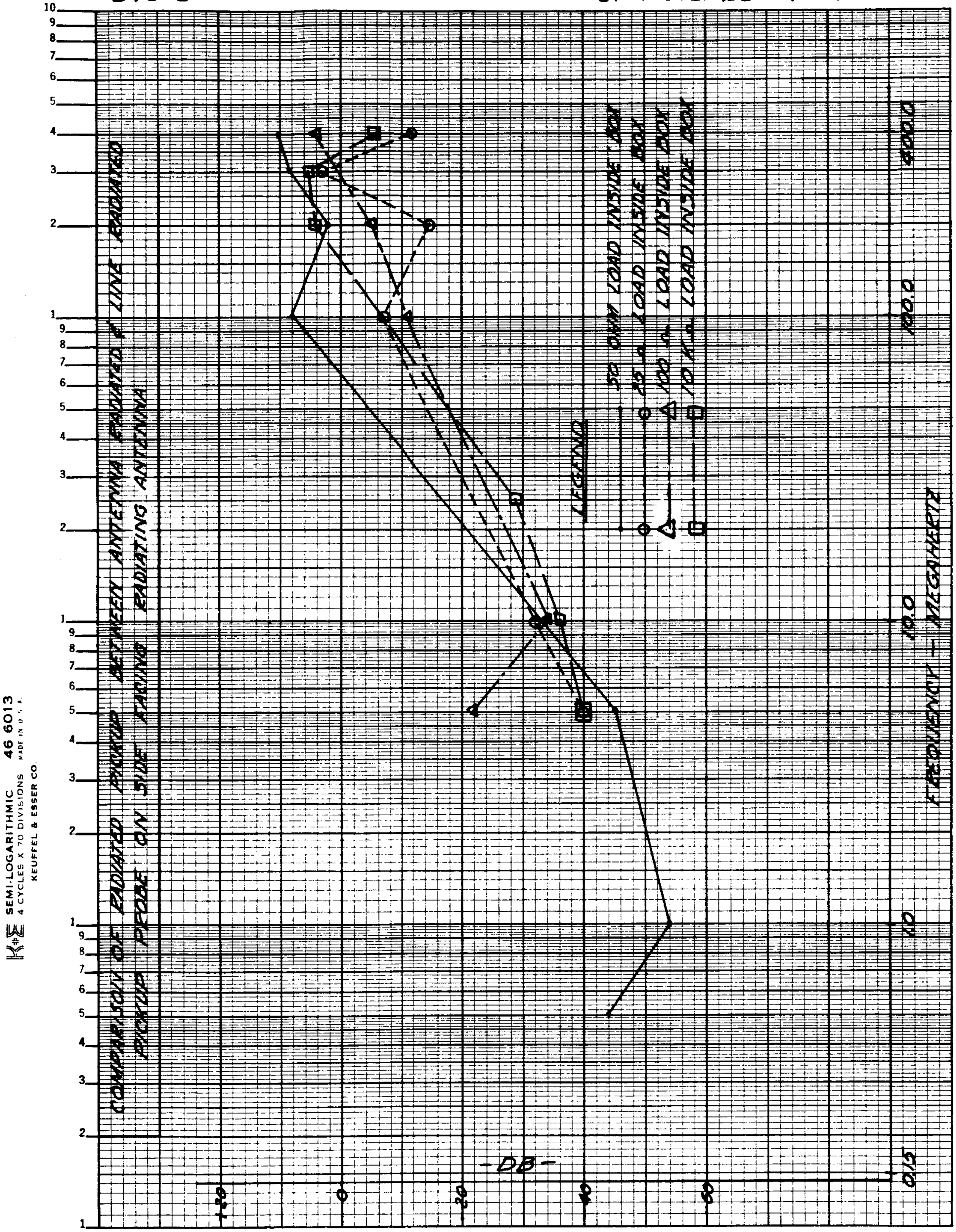
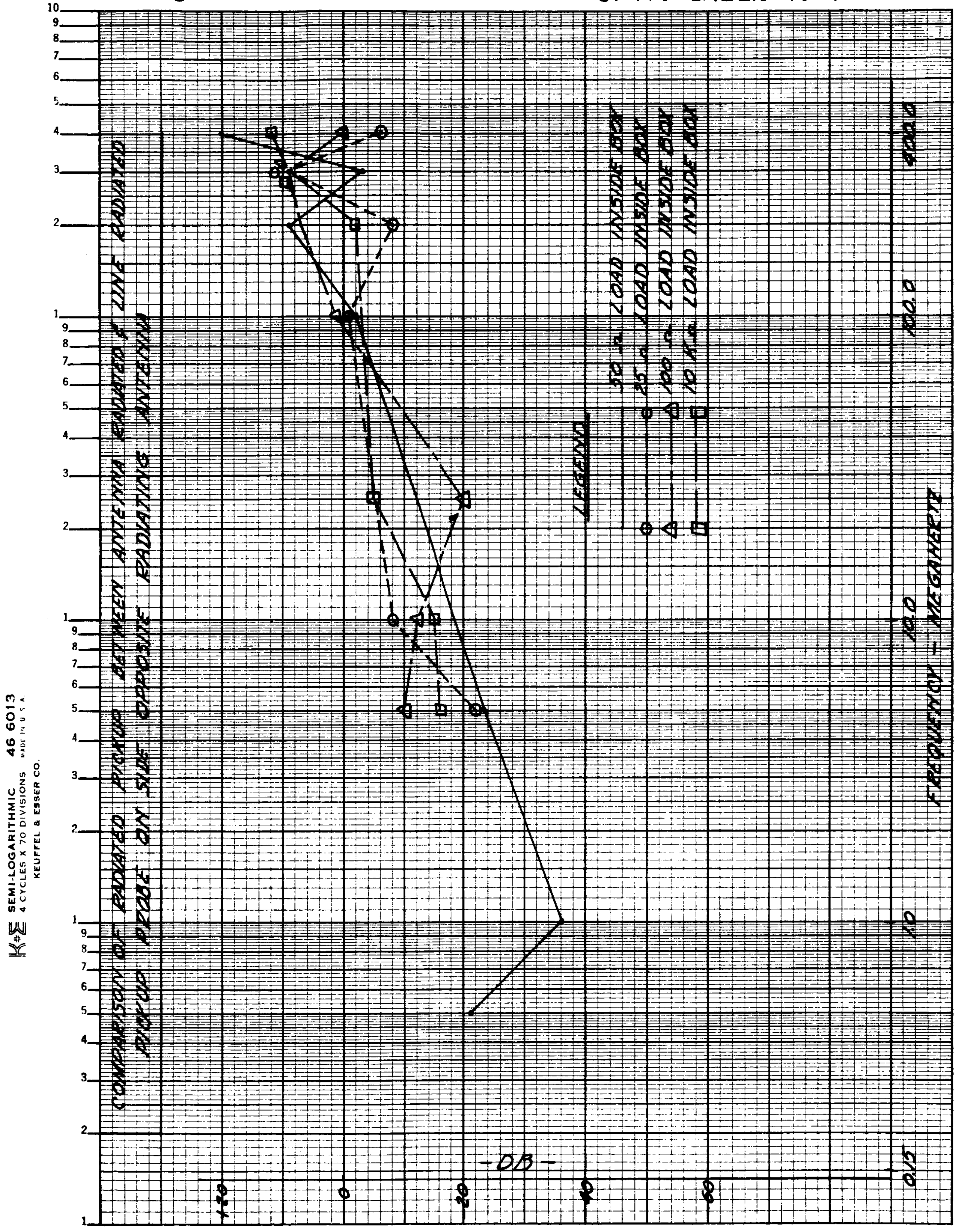


FIGURE 17 TEST SETUP, COMPARISON OF LINE LOADING



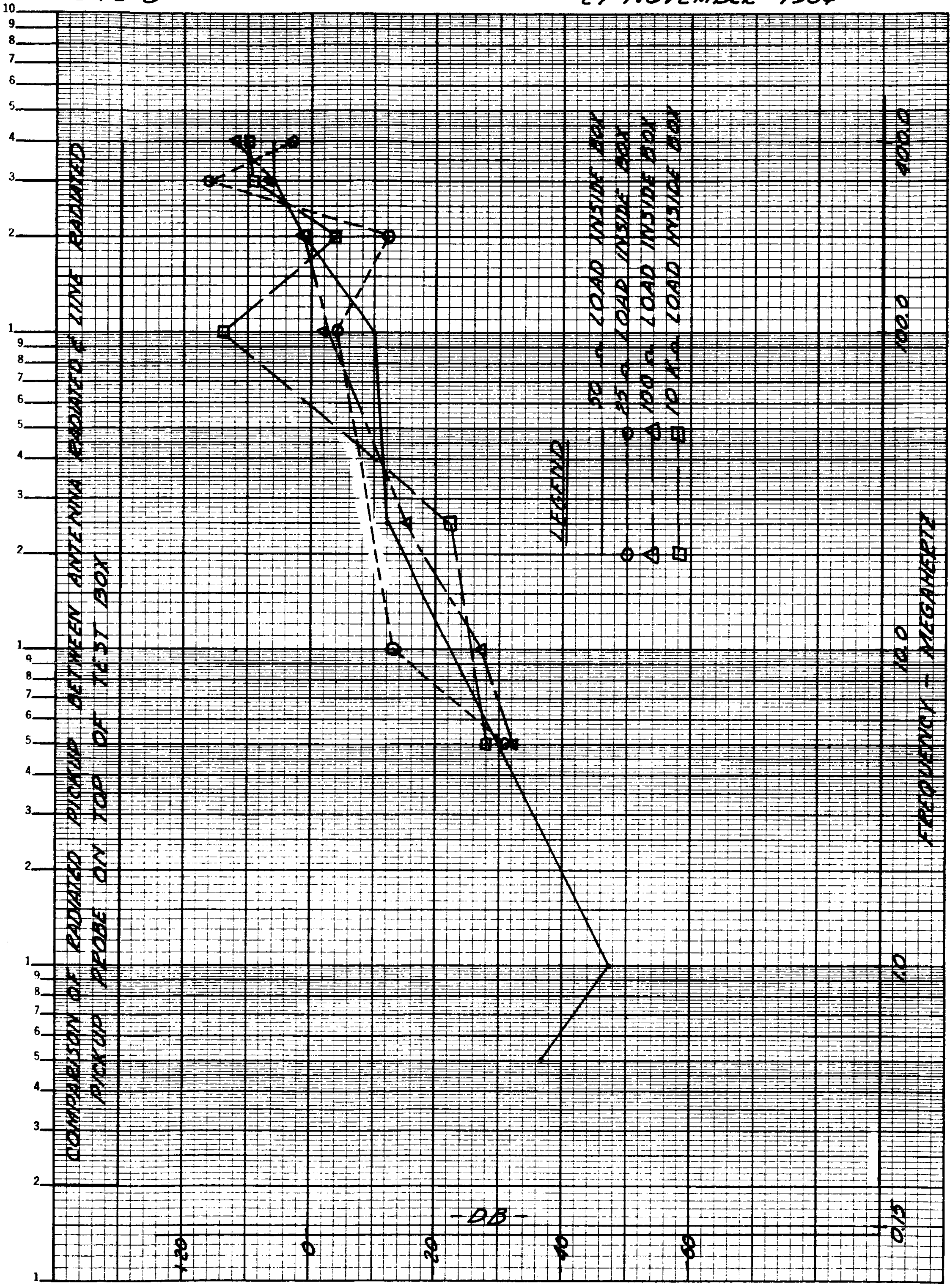
LINE RADIATED PICKUP RELATIVE TO ANTENNA RADIATED PICKUP

FIGURE 18



LINE RADIATED PICKUP RELATIVE TO ANTENNA RADIATED PICKUP

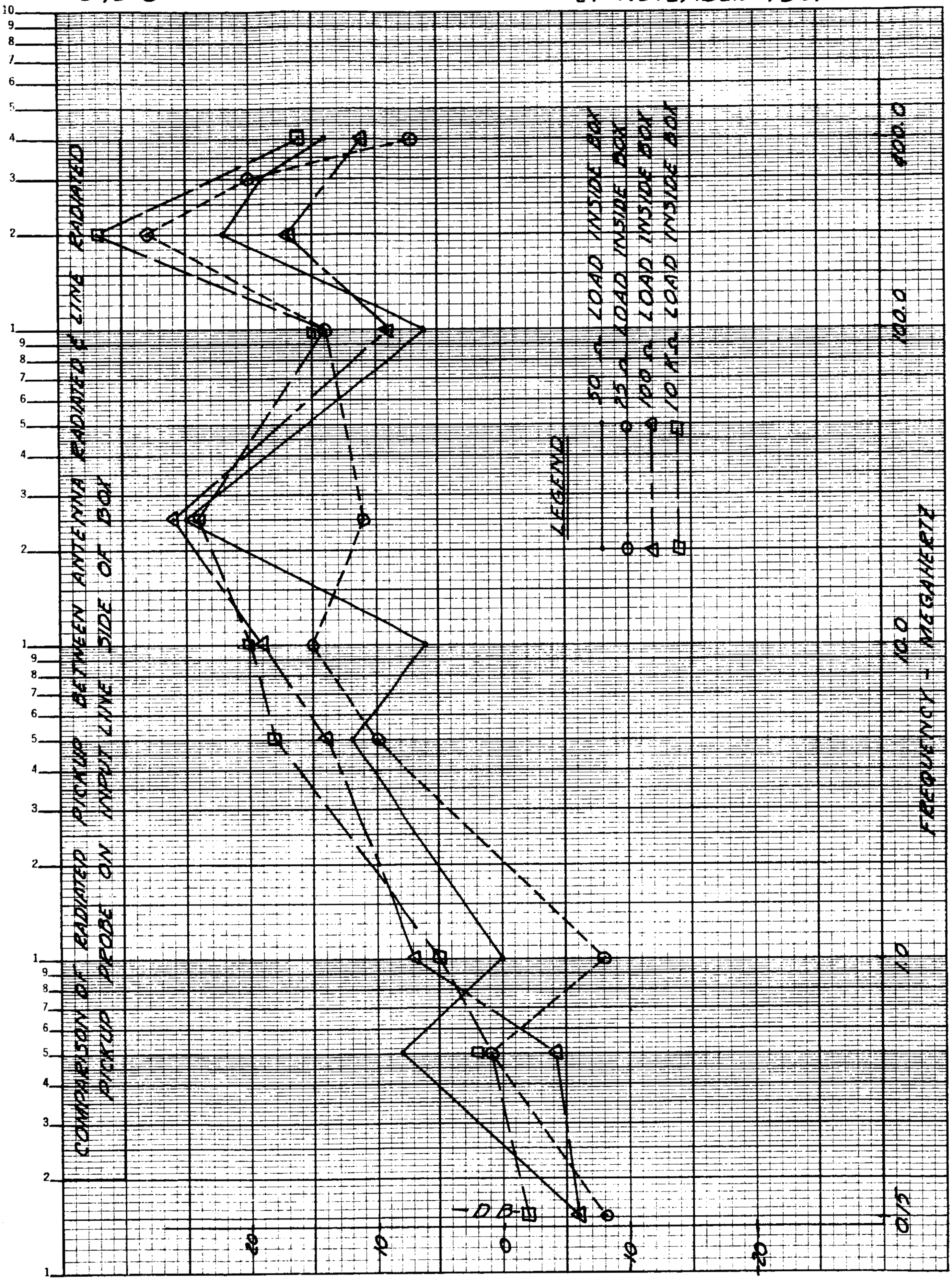
FIGURE 19



K+E SEMI-LOGARITHMIC 46 6013
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

LINE RADIATED PICKUP RELATIVE TO ANTENNA RADIATED PICKUP

FIGURE 20



K+E SEMI-LOGARITHMIC 46 6013
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

LINE RADIATED PICKUP RELATIVE TO ANTENNA RADIATED PICKUP
FIGURE 21

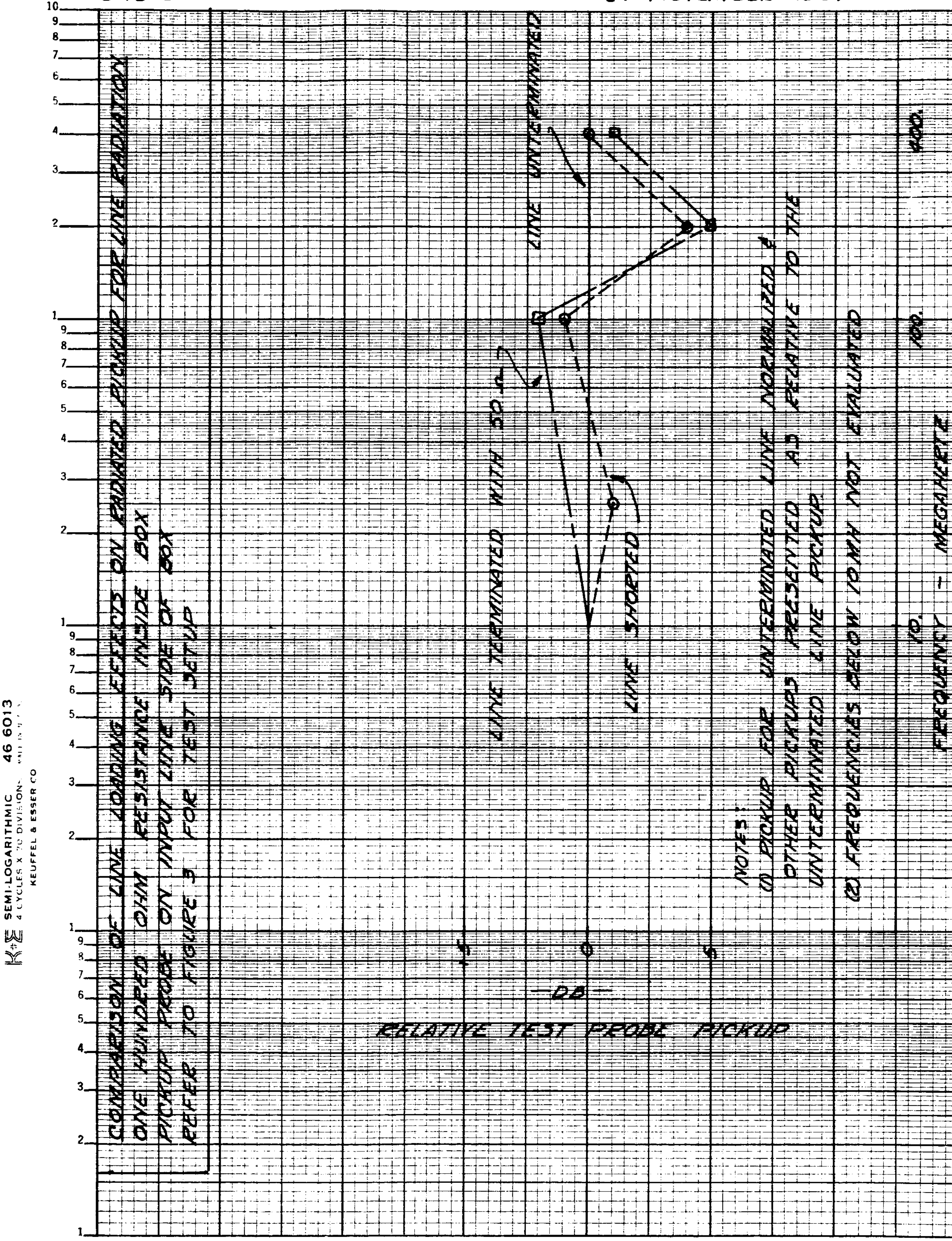

COMPARISON OF LINE LOADING EFFECTS ON RADIATED PICKUP FOR LINE RADIATION
ONE HUNDRED OHM RESISTANCE INSIDE BOX
PICKUP PROBE ON INPUT LINE SIDE OF BOX
REFER TO FIGURE 3 FOR TEST SETUP
LINE TERMINATED WITH 50 Ω
LINE SHORTED
LINE UNTERMINATED
NOTES:
(1) PICKUP FOR UNTERMINATED LINE NORMALIZED & OTHER PICKUPS PRESENTED AS RELATIVE TO THE UNTERMINATED LINE PICKUP
(2) FREQUENCIES BELOW 10MH NOT EVALUATED
10.
100.
400.
FREQUENCY - MEGAHERTZ
-5
0
5
-DB-
RELATIVE TEST PROBE PICKUP
SEMI-LOGARITHMIC 46 6013
KEUFFEL & ESSER CO.

FIGURE 22

radiation. The results are significant in the case of pickup at the discontinuities presented by the input plugs. The data warrents further analysis for the purpose of considering eliminating the RF radiated, low power susceptibility test from the EMC procedure over the frequency range from 0.15 to 400 MHz. Perhaps radiated RF susceptibility testing should be limited to higher power levels at known radiating frequencies.

The data obtained from successively shorting, loading the line with 50 ohms, and leaving the line unterminated indicates that power supply impedances have little effect on line radiation (for frequencies above 10 MHz). It was also found that injection of the signal either at the package terminals or at the power supply end of the input line resulted in output deviations of only approximately 1 db.

3. TESTS RETAINED WITHOUT CHANGE

There are some traditional EMI type tests that will probably remain in component specifications essentially as they are even though there is no direct counterpart of these tests in the EMC systems evaluation. These tests serve the purpose of describing certain design and performance aspects of equipments. Some of these tests are (not all existing specifications contain all of these tests):

a. Antenna Conducted Suprious Emission Tests

b. Cross-modulation Tests

c. Intermodulation Tests

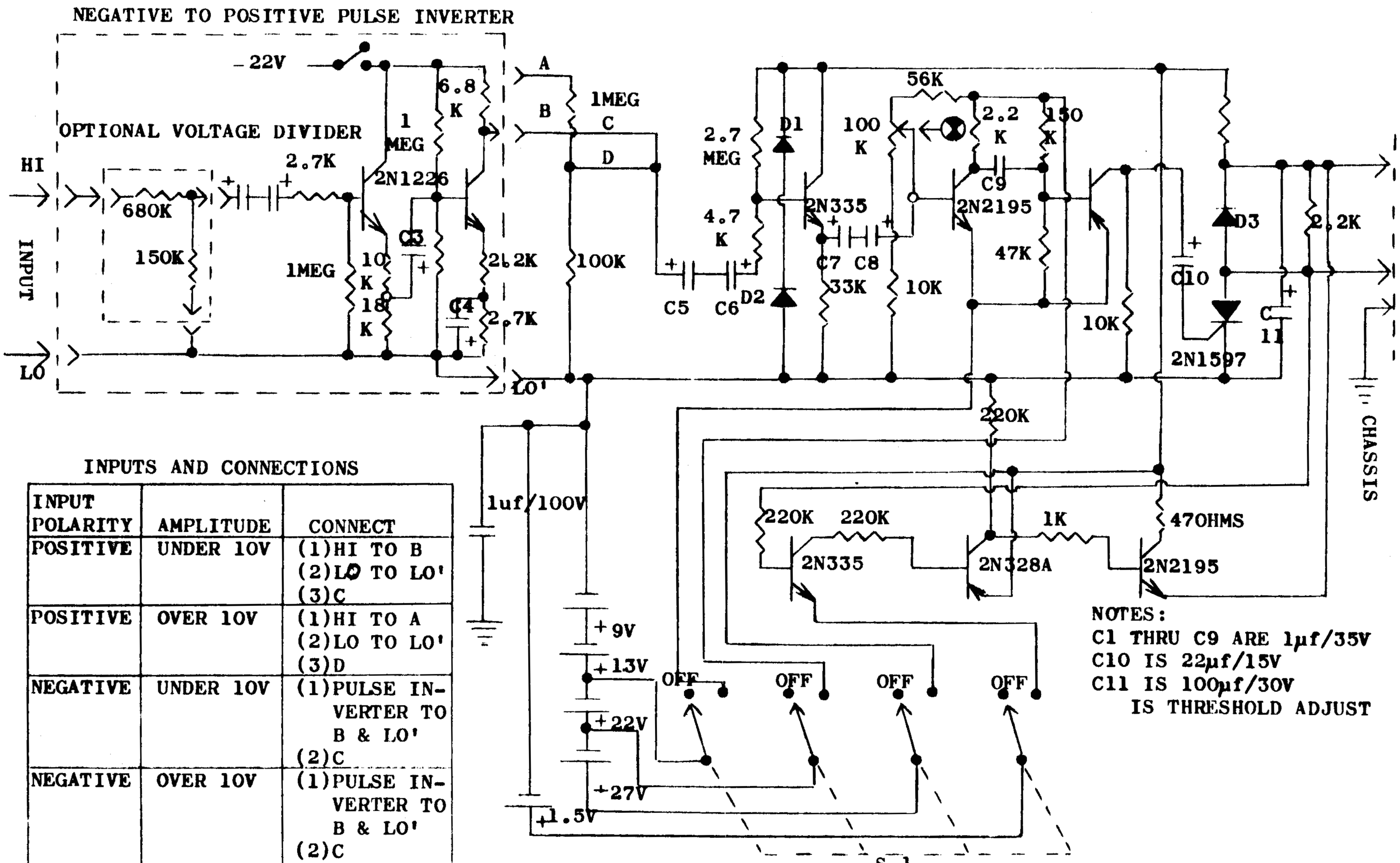
d. Receiver Front-end Rejection Tests

4. MISCELLANEOUS ITEMS OF INTEREST

4.1 THE DETECTOR PROBLEM. Numerous detection problems exist in EMC testing from the point of view of available hardware. Perhaps the most challenging problem is that of obtaining information quickly but equivalent to that obtained by slowly scanning a receiver over an extremely wide frequency range. Other problems consist of measuring voltage magnitudes at a given frequency or over a range of frequencies such as in the case of transients. All of these detection problems become magnified when one considers that a system such as SATURN may require that detectors be permanently installed as flyable hardware.

4.1.1 Detectors Now in Use At GD/A. EMC testing at GD/A has involved the use of specially designed transient detector modules and steady state detector modules installed across the critical circuits. These modules are pre-set to give an output when the input exceeds a level which is less than 6 db below the predetermined susceptibility threshold level. The circuit diagrams of the transient detector module and the steady state module are shown in Figures 23 and 24, respectively. The salient characteristics of the transient detectors are as follows: Small size with self-contained power supply; input impedance greater than 750 K ohms at 1 MHz with DC isolation; isolated input and output; variable sensitivity of 200 millivolts to 10 volts at 1 microseconds duration with resistive voltage divider for triggering sensitivity exceeding 10 volts; and output pulse capable of driving a pen recorder relay at a rate of 5 events per second. The characteristics of the steady state detectors are as follows: Small size with self-contained power supply; input impedance greater than 300 Kohms with DC isolation; isolated input and output; sensitivity of 50 millivolts RMS to 4 volts RMS; linear response ($\pm$ 10%) to frequencies between 25 Hertz and 50 KHz; and 25 volts output for the duration of the input signal above threshold. Data from these tests is in the form of sequence recorder data received from the transient and steady state detector modules. This data and normally recorded events are analyzed to determine whether the "No-malfunction" requirement of MIL-E-6051C has been exceeded.

4.1.2 Detector Development. The desirability of permanently attached vehicleborne sensors is recognized with the concomitant requirements for low weight and small volume. The sensors described above are approximately 1 pound in weight and 27 cubic inches in volume. The designer of these sensors has considered as part of this study,



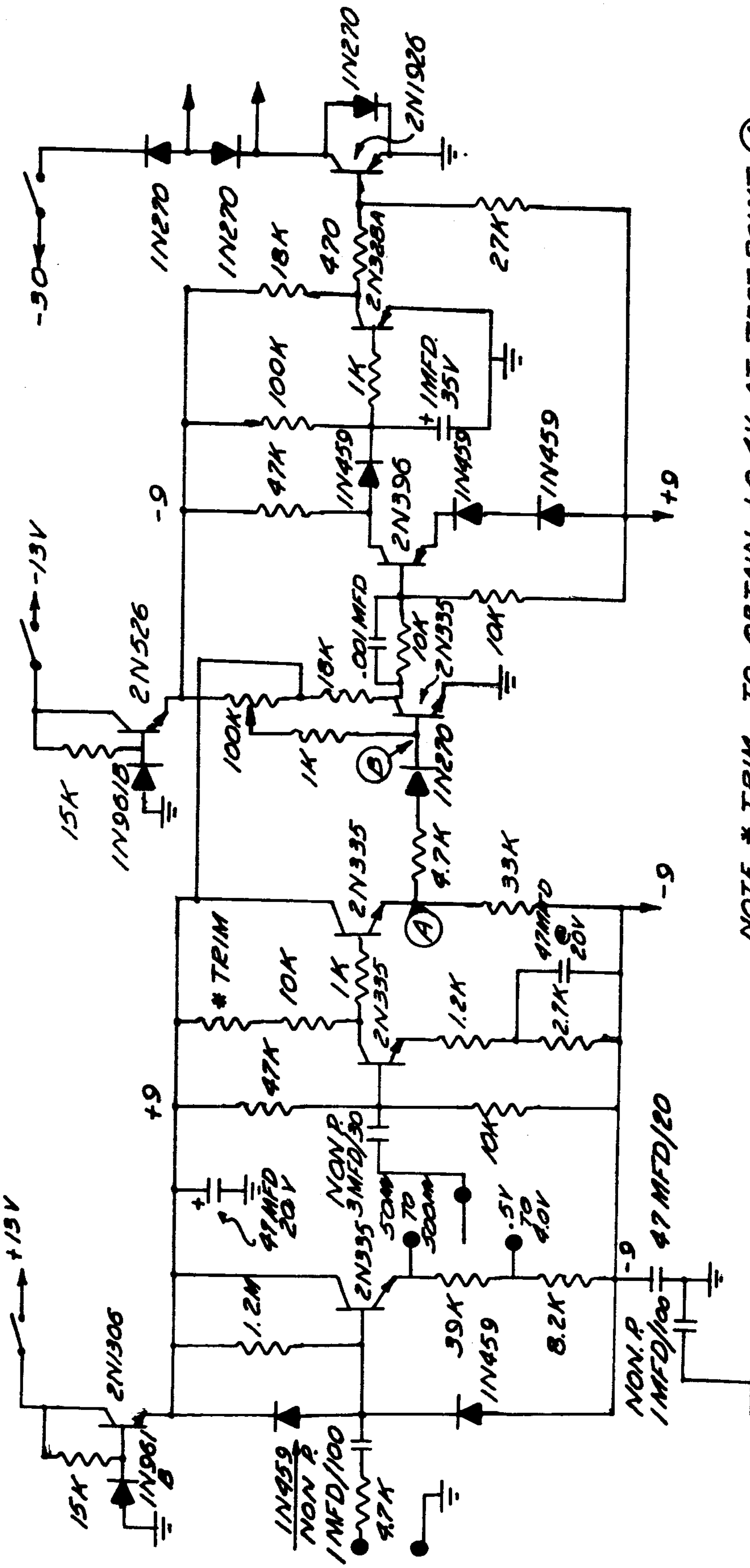
NOTES:
C1 THRU C9 ARE 1µf/35V
C10 IS 22µf/15V
C11 IS 100µf/30V
IS THRESHOLD ADJUST

TRANSIENT DETECTOR CIRCUIT DIAGRAM

INPUTS AND CONNECTIONS

INPUT POLARITY	AMPLITUDE	CONNECT
POSITIVE	UNDER 10V	(1)HI TO B (2)LO TO LO' (3)C
POSITIVE	OVER 10V	(1)HI TO A (2)LO TO LO' (3)D
NEGATIVE	UNDER 10V	(1)PULSE IN-VERTER TO B & LO' (2)C
NEGATIVE	OVER 10V	(1)PULSE IN-VERTER TO B & LO' (2)C (3)VOLTAGE DIVIDER

FIGURE 23 TRANSIENT DETECTOR CIRCUIT DIAGRAM



NOTE * TRIM TO OBTAIN +0.4V AT TEST POINT (A) WITH 0.V BIAS AT TEST (B)

FIGURE 24 STEADY STATE DETECTOR MODEL B

the feasibility of reducing the volume to 4.5 cubic inches and the weight proportionately. The approach has been to use existing miniaturization techniques since exotic micro-technique development clearly cannot be undertaken on this study. Based upon the breadboard work resulting in the performance parameters indicated below, the above volume-weight reduction can be realized.

Breadboard study of a transient detector meeting four important needs has been carried out. These important needs (aside from its actual performance characteristics) are:

a. It can be small (little over 4 cubic inches).
b. It can be light (probably under 3 ounces)
c. It can operate off vehicle power for A/B use without concern for battery life.
d. It can be adapted to a digital data acquisition system.

The detector consists of one channel of information which can be set to any positive threshold amplitude between 0.2 and 8 V using a trimpot. Higher amplitudes may be obtained by an input divider network. Negatively going transients may be similarly monitored by using an alternate information channel. Amplitude response is linear from a few hundred Hertz to over 2 megaHertz. Transients of higher frequency may be monitored with a corresponding reduction in threshold amplitude. Output memory is achieved with a silicon controlled rectifier and can be reset by application of a ground to a turnoff stage. A bistable could also be used for memory. Input impedance per channel is one megohm. Detection rates, limited by the rate of sampling and re-setting of the memory, can be on the order of 100,000 second.

It is anticipated that the breadboard described above will actually be packaged to confirm the predicted small weight and volume.

4.2 THE TRANSIENT GENERATOR. The transient generator has become an essential part of the necessary equippage for complete interference control work even though the transient susceptibility test has not yet been incorporated in all specifications. Transient susceptibility has been considered somewhat in Paragraph 2.3.2 of this report and also, in a sense, in Paragraph 2.2.2, where the possible equivalence of transient and audio susceptibility was suggested. The following description of a square wave transient generator designed, built, and used at GD/A, is believed to represent a more versatile solution to testing needs than those represented by the more simple transient generator described in various interference specification.

It has been found that one of the limitations in susceptibility testing comes through lack of versatility and capacity in the transient generator. The following brief description and block diagram (Figure 25) are for a GD/A designed and built piece of equipment. The high current pusle generator provides pulse width variable from 20 to 500 microseconds and pulse amplitudes variable from 1 to 100 volts. Pulse repetition rates of 1 to 20 per seconds are obtained from an internal unijunction multivibrator. A front panel push button switch provides single pulse operation.

A full-wave bridge and 2000 microfarad capacitor are used for a charging supply for an output pulse source capacitor that is discharged across an external load. The charging source voltage is determined by a Variac.

Pulse forming is accomplished by turning on a silicon controlled rectifier (the "ON" SCR) placed in series with the output capacitor and the load, and after the desired delay gating on a second SCR (the "OFF" SCR) that parallels the load. The trailing edge of the pulse is reduced nearly to zero by the "OFF" SCR, this amplitude being determined by the IR drop across the SCR (approximately 0.7 volts). A nearly square pulse is produced while rise and fall times are determined by the rise times of the "ON" and "OFF" SCR's and whose slope depends upon the RC product of the output capacitor and load impedance.

Charging of the output capacitor from the charging source is accomplished between output pulses by means of a relay synchronized with the pulse rate multivibrator. The generator is connected to external loads by means of a very low impedance pulse transformer or a large coupling capacitor. Pulse polarity is determined by the output lead connections.

4.3 R.F. INTERMODULATION. A computer program is employed to determine potential intermodulation products that could occur with non-linear mixing of intentional R.F. radiators.

The program reads in n frequencies and applies the applicable intermodulation sum and difference product equations. At present only 2A-B and 3A-2B are used since, A and B being approximately the same, these equations may be expected to yield products, near the values of A and B. Higher orders such as (nA-(n±1B) are neglected as being surely negligible. All values of A and B (the n assigned R.F. frequencies) are used so that all combinations of the n frequencies are used. A bandwidth tolerance is introduced so that the comparison between the possible products and the n frequencies may be made to any selected bandwidth. The program is general to the point various frequencies and bandwidths can be applied in one run. Figure 26 shows the flow of data input and computations.

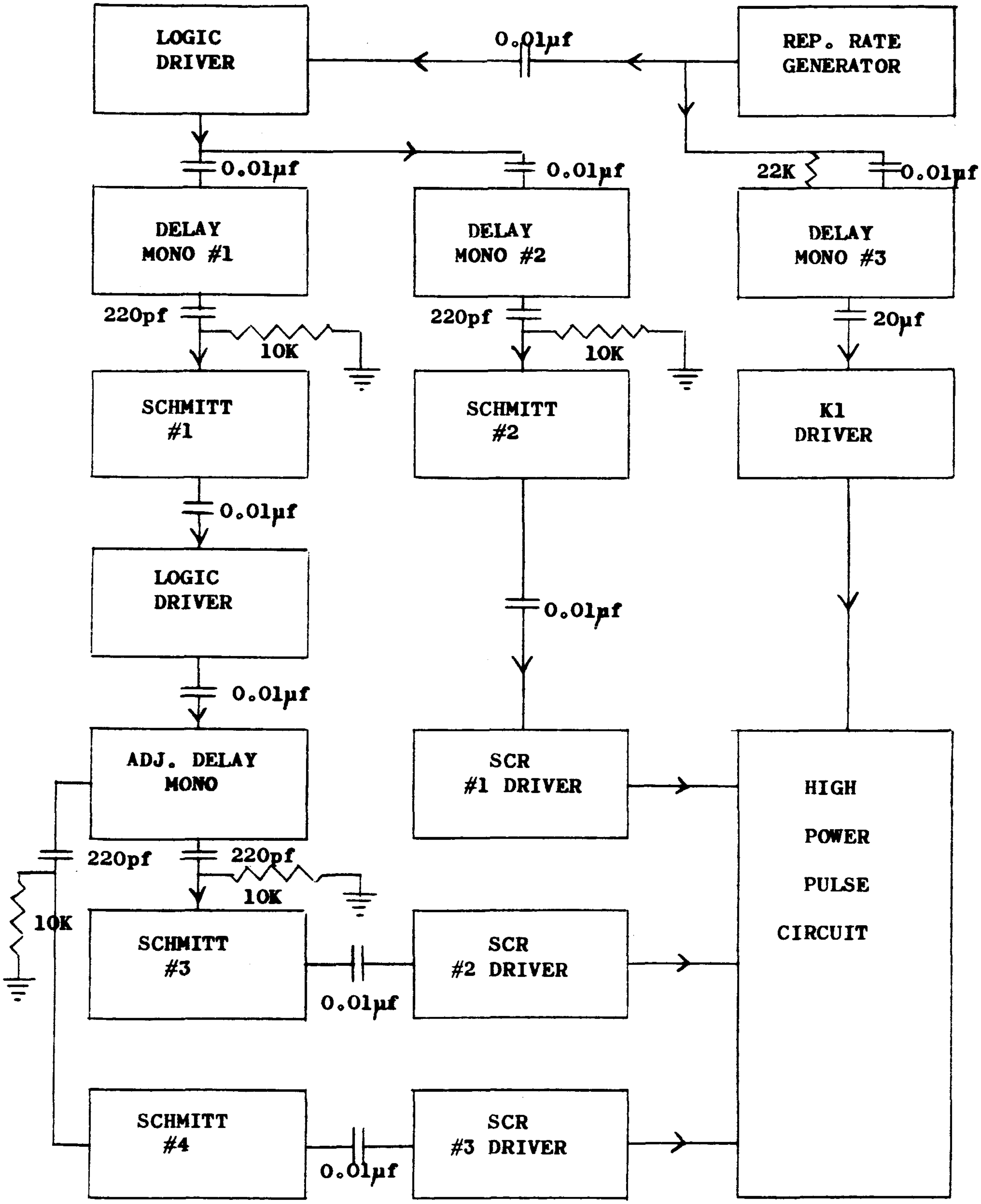


FIGURE 25 TRANSIENT GENERATOR BLOCK DIAGRAM

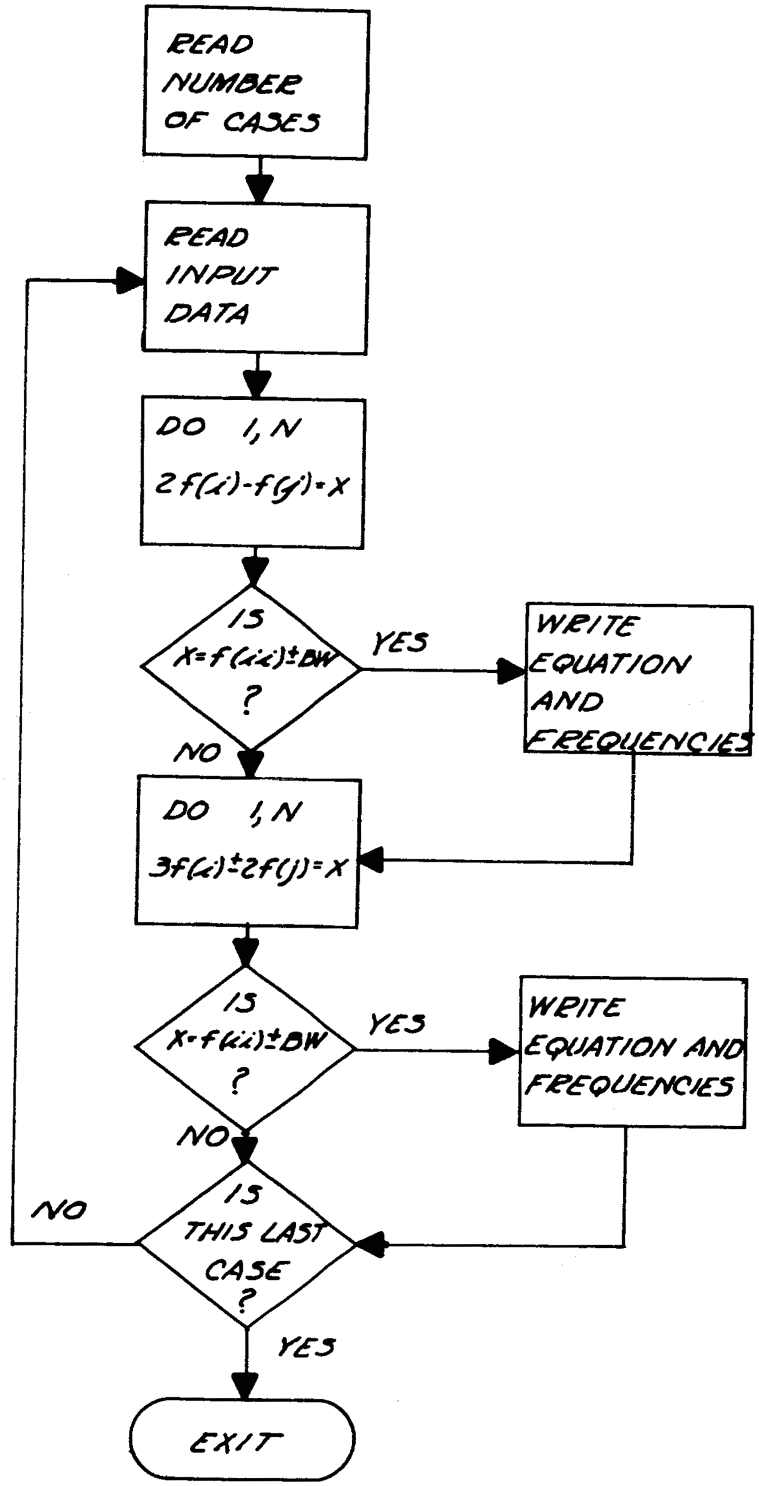


FIGURE 26. FLOW DIAGRAM, INTERMODULATION CALCULATOR

4.3.1 Comments Bearing on MSFC EMC Specification No. 279.

Frequency Allocation. Paragraph 4.4.4 of Specification No. 279 discusses control of frequency allocation to reduce the possibility of undesired interactions. A brief study of potential intermodulation products from the large number of SATURN V telemetry frequencies has been performed. The rather surprising result of numerous potential interferences was observed. These are not submitted to suggest that this situation has been overlooked. This will be pursued and discussed further as appropriate or as requested by MSFC.

Only those products expected to fall close to intended radiating frequencies were formed. i.e. The third order product (2A-B) and the fifth order product (3A-2B) where A and B respectively assume all of the SATURN V RF frequencies of interest. Some of the products fall exactly on assigned frequencies. Products up to 0.2 Mc from assigned frequencies are noted. The following summarizes the results obtained.

a. Entire SATURN V Vehicle. Twenty-seven frequencies were used to form the products given above. Forty-eight intermodulation products were identical to some one of the original twenty-seven inputs (to the nearest 0.1 MHz). One hundred and twenty-six intermodulation products fell somewhere within 0 to ± 0.2 MHz of the input frequencies(to the nearest 0.1 MHz).

b. Spacecraft. Six frequencies were used to form the intermodulation products. No products were identical to the six inputs. Two potential products fell within 0.2 MHz of two of the input frequencies.

c. Instrument Unit. Four input frequencies were used. No products were identical to the input. Two products fell within 0.2 MHz of two of the inputs.

d. S-IV B Stage. Five input frequencies were used. One product was identical to one of the inputs. No other products were within 0.2 MHz of one of the input frequencies.

e. S-II Stage. Six input frequencies were used. No intermodulation products were identical to an input frequencies. One product fell within 0.2 MHz of one of the inputs.

f. S-IC Stage. Six input frequencies were used. No products were identical to an input. Two products fell within 0.1 MHz of inputs.

The actual input frequencies and actual intermodulation product frequencies are given in Tables II - VII.

4.4 CIRCUIT ANALYSIS. The relatively new field of computer analysis of circuits not only promises to be a valuable design aid but offers hope of leading to that much sought after "interference free" design. Or at least it promises to aid in understanding where potential compatiblity problems may arise, to aid in anticipating suppression needs, and perhaps even to aid in supplying susceptibility thresholds when there is no opportunity to determine these by direct measurement.

4.4.1 Susceptibility Prediction. An Electronic Circuit Analysis Program consisting of an integrated system of programs providing the facility for DC,AC and transient analysis of electrical networks has been developed and implemented at GD/A. This program was primarily developed to enable a circuit designer to evaluate design performance of electronic circuits without the necessity of constructing breadboards or prototypes. The program can evaluate circuit performance rapidly and for various component values to determine required tolerances for optimum reliability.

Examination and analysis of the program indicates that it should be adaptable to conducted susceptibility testing on blueprint circuits. Such capability would provide susceptibility information during the design phases, isolate susceptibility components or basic circuits, and provide for suppression to be included directly in the initial design at minimum cost and delay.

The program was evaluated by first performing a standard conducted susceptibility test on an electronic circuit and then applying the circuit analysis program to the theoretical equivalent of the circuit. The results substantiate the theory that such testing can be performed, and problems remedied, prior to construction of hardware.

The test circuit shown in Figure 23, the transient detector, was analyzed. Empirical conducted audio frequency susceptibility data shows that the electronic circuit is not susceptible to 3V RMS on the +27 vdc source and that the circuitry was susceptible to approximately 2.8V RMS on the +13 vdc source over the frequency range from 20 Hz to 150 KHz. Above 3 KHz empirical results indicated susceptibility threshold was greater than 3V RMS. The Circuit Analysis results indicated that the electronic circuitry was not susceptible to 3 V RMS across the +27 vdc source. The Circuit Analysis program did indicate susceptibilies to approximately 2.3V RMS on the +13 vdc source over the frequency range from 30 Hz to 150 KHz. The correlation is encouraging. Both methods indicated no susceptibilities on +27 vdc source, and both methods indicated susceptibility on the +13 vdc source. The discrepancies in susceptibility levels can probably be atrributed to differences in the mathematical equivalent and the actual circuit. These differences could be a result of any of the following or others:

TABLE II

n	f(II)	2f(I)-f(J)=f(II)		3f(I)-2(J)=f(II)		2f(I)-f(J)=f(II)± 0.15MHz		3f(I)-2f(J)=f(II)± 0.15MHz	
		f(I)	f(J)	f(I)	f(J)	f(I)	f(J)	f(I)	f(J)
1	228.2	227.2	226.2	236.2	240.2	237.8 227.2 236.2	247.3 226.2 244.3	245.3 236.2 244.3	253.8 240.2 252.4
2	247.3			245.3 250.7	244.3 252.4	237.8 246.3	228.2 245.3	250.7 245.3	252.4 244.3
3	257.3	258.5 256.2	259.7 255.1	244.3	237.8	258.5 256.2	259.7 255.1	248.6 244.3	244.3 237.8
4	230.9	245.3 236.2 231.9	259.7 241.5 232.9			245.3 232.9 236.2 231.9	259.7 235.0 241.5 232.9		
5	237.8			252.4	259.7	241.5 244.3	245.3 250.7	252.4	259.7
6	2272.5								

LIST I - FREQUENCIES FOR SPACECRAFT, IU, SIVB, SII & SIC

n	f(II)	2f(I)-f(J)=f(II)		3f(I)-2(J)=f(II)		2f(I)-f(J)=f(II)±0.15 MHz		3f(I)-2f(J)=f(II)±0.15MHz	
		f(I)	f(J)	f(I)	f(J)	f(I)	f(J)	f(I)	f(J)
7	245.3	246.3	247.3			236.2 241.5 246.3 250.7 240.2	227.2 237.8 247.3 256.2 235.0	237.8 235.0	234.0 229.9
8	250.7			255.1	257.3	244.3	237.8	255.1 240.2 235.0	257.3 235.0 227.2
9	255.1	250.7 256.2	246.3 257.3			256.2 253.8 250.7	257.3 252.4 246.3	248.6	245.3
10	259.7	245.3 246.3 258.5	230.9 232.9 257.3			247.3 245.3 258.5 246.3	235.0 230.9 257.3 232.9		
11	226.2	227.2	228.2			236.2 227.2	246.3 228.2	232.9	236.2
12	232.9	246.3 231.9	259.7 230.9	230.9	229.9	234.0 246.3 231.9	235.0 259.7 230.9	237.8 230.9 236.2	240.2 229.9 237.8

LIST I - FREQUENCIES FOR SPACECRAFT, IU, SIVB, SII & SIC

TABLE II (Continued

TABLE II (Continued)

n	f(II)	2f(I)-f(J)=f (II)		3f(I)-2(J)=f (II)		2f(I)-f(J)=f (II)±0. 15MHZ		3f(I)-2f(J)=f(II)±0. 15MHz	
		f(I)	f(J)	f(I)	f(J)	f(I)	f(J)	f(I)	f(J)
13	246.3	245.3 250.7 252.4	244.3 255.1 258.5	232.9	226.2	245.3 250.7 236.2 252.4 240.2	244.3 255.1 226.2 258.5 234.0	232.9	226.2
14	253.8					256.2	258.5		
15	258.5	252.4	246.3	246.3	240.2	247.3 257.3 246.3 252.4 256.2	236.2 256.2 234.0 246.3 253.8	246.3 256.2	240.2 255.1
16	227.2					236.2	245.3	247.3 241.5	257.3 248.6
17	234.0					237.8 232.9 246.3 231.9 240.2	241.5 231.9 258.5 229.9 246.3	246.3 241.5 231.9	252.4 245.3 230.9
18	241.5	236.2	230.9			237.8 236.2	234.0 230.9		

LIST I (Continued

n	f(II)	2f(I)-f(J)=f(II)		3f(I)-2f(J)=f(II)		2f(I)-f(J)=f(II)±0.15MHz		3f(I)-2f(J)=f(II)±0.15MHz	
		f(I)	f(J)	f(I)	f(J)	f(I)	f(J)	f(I)	f(J)
19	229.9	230.9	231.9	241.5 231.9	247.3 232.9	247.3 230.9 231.9 235.0	258.5 231.9 234.0 240.2	240.2 231.9 241.5	245.3 232.9 247.3
20	236.2	244.3	252.4	234.0	232.9	244.3 234.0 240.2	252.4 231.9 244.3	234.0 230.9	232.9 228.2
21	248.6	252.4	256.2	235.0	228.2	252.4 240.2	256.2 231.9	235.0	228.2
22	244.3	245.3	246.3	232.9 246.3	227.2 247.3	245.3 236.2 240.2	246.3 228.2 236.2	253.8 246.3 232.9 248.6	258.5 247.3 227.2 250.7
23	252.4	246.3 244.3	240.2 236.2			244.3 253.8 246.3	236.2 255.1 240.2	257.3 244.3	259.7 240.2
24	256.2	252.4	248.6	236.2	226.2	257.3 250.7 252.4	258.5 245.3 248.6	258.5 236.2	259.7 226.2

LIST I (Continued)

TABLE II (Continued)

LIST I (Continued)

n	f(II)	2f(I)-f(J)=f (II)		3f(I)-2f(J)=f (II)		2f(I)-f(J)=f(II)±0.15MHz		3f(I)-2f(J)=f(II)±0.15MHz	
		f(I)	f(J)	f(I)	f(J)	f(I)	f(J)	f(I)	f(J)
25	231.9	230.9	229.9	241.5	246.3	247.3 230.9 232.9 234.0 240.2	259.7 229.9 234.0 236.2 248.6	234.0 240.2 241.5	235.0 244.3 246.3
26	235.0					232.9 234.0 240.2	230.9 232.9 245.3	250.7	258.5
27	240.2	246.3	252.4	234.0 252.4	230.9 258.5	246.3 235.0	252.4 229.9	230.9 234.0 252.4 244.3	226.2 230.9 258.5 246.3

TABLE II (Continued)

n	f(II)	2f(I)-f(J)=f (II)		3f(I)-2f(J)=f (II)			2f(I)-f(J)=f(II)±0.2 MHz		3f(I)-2f(J)=f(II)±0.2MHz	
		f(I)	f(J)	f(I)	f(J)		f(I)	f(J)	f(I)	f(J)
	228.2						237.8	247.3		
	247.3						237.8	228.2		
	257.3									
	230.9									
	237.8									
	2272.5									

SPACECRAFT FRREQUENCIES

TABLE III

n	f(II)	2f(I)-f(J)=f(II)		3f(I)- 2f (I) = f(II)			2f(I)-f(J)=f(II)±0. 2 MHz		3f(I)-2f(J)=f(II)±0. 2MHz	
		f(I)	f(J)	f(I)	f(J)		f(I)	f(J)	f(I)	f(J)
	245. 3									
	250. 7						255. 1	259. 7		
	255. 1									
	259. 7						255. 1	250. 7		

IU FREQUENCIES

TABLE IV

		$2f(I)-f(J)=f(II)$		$3f(I)-2f(J)=f(II)$			$2f(I)-f(J)=f(II)\pm0.2$ MHz		$3f(I)-2f(J)=f(II)\pm0.2$ MHz	
n	f(II)	f(I)	f(J)	f(I)	f(J)		f(I)	f(J)	f(I)	f(J)
	226.2									
	232.9									
	246.3			232.9	226.2				232.9	226.2
	253.8									
	258.5									

S IV B FREQUENCIES

TABLE V

		$2f(I)-f(J)=f(II)$		$3f(I)-2f(J)=f(II)$			$2f(I)-f(I)=f(II)\pm 0.2$ MHz		$3f(I)-2f(I)=f(II)\pm 0.2$ MHz	
n	f(II)	f(I)	f(J)	f(I)	f(J)		f(I)	f(J)	f(I)	f(J)
	227.2								241.5	248.6
	234.0									
	241.5									
	229.9									
	236.2									
	248.6									

SII FREQUENCIES

TABLE VI

n	f(II)	2f(I)-f(J)=f(II)		3f(I)-2f(J)=f(II)		2f(I)-f(J)=f(II)±0.1 MHz		3f(I)-2f(J)=f(II)±0.1 MHz	
		f(I)	f(J)	f(I)	f(J)	f(I)	f(J)	f(I)	f(J)
	245.3					240.2	235.0		
	252.4								
	256.2								
	231.9								
	235.0								
	240.2								

SIC FREQUENCIES

TABLE VII

1. Component values used in mathematical model are nominal in most cases. To alleviate this error both worst case and best case values should also be evaluated.
2. Since the evaluation was performed for audio frequencies transistor junction capacitance was neglected.
3. Stray reactance were also neglected for this evaluation.

Since the evaluation is being performed on a circuit not yet packaged stray reactances will not be known and will alter the results. This should not be a serious problem since most susceptibilities can be uncovered even neglecting these values. This tends to reduce the program's effectiveness at high frequencies, however, if low frequency suppression is properly constructed using high quality feed through capacitors, it should provide good isolation to high frequencies.

One additional advantage of such a program is that it identifies the area in the circuit being affected. In the example given the bias on Q3 is shifted by approximately 4 volts causing it to change state when the +13 vdc source is subjected to the 3 V RMS test functions.

4.4.2 Analytical Prediction and Suppression of Inductively Caused Transients. The operation of inductive devices in electronic systems causes harmful transients which can couple throughout the system via conduction, induction and radiation. These voltage transients are generated by the collapsing magnetic field of the inductor when the current is suddenly interrupted.

Most complex electronic devices are susceptible to these transients. Some, such as digital circuits, are permanently damaged because breakdown voltages of solid state components are exceeded; others, such as sensitive receivers, can be temporarily degraded due to Electromagnetic Interference. These voltage and current transient problems are common in the aerospace industry where the majority of the components that comprise a system are operated from a common power supply, thus presenting an Electromagnetic Compatibility problem. Most of these problems are readily recognized by designers that are aware of radio interference. The techniques usually employed for suppression are "brute force" methods such as LC filters, simple RC networks, or just a back biased diode with a limiting resistor across the coil. Of all these methods, probably the most widely used is the diode-resistor.

A technique is being analyzed to allow simple prediction of transient responses (amplitude, rise time) duration) of "blue-print" inductive devices knowing primarily the designed inductance and DC resistance of the device and the stray winding capacitance. Being able to mathematically describe a transient under "no-suppression" and "suppression" conditions it is anticipated that network synthesis techniques can be applied to optimize suppression in relation to amplitude reduction, drop-out time, etc.

The current state of the technique allows for an approximation of rise time, a determination of drop-out time, maximum amplitude, and the determination of minimum series resistance for diode suppression knowing maximum allowable hold-in time.

4.5 USE OF CONICAL ANTENNAS.

4.5.1 Two Horn Gain Determination. MIL-STD-826 calls out the use of the conical log spiral antenna as a receiving antenna as a possible replacement for the dipole antenna for radiated interference measurements. These antennas were primarily developed for use in radiated susceptibility tests and since this was the case the antennas, as such, were never calibrated for radiated measurements.

GD/A has purchased two Stoddart Model 93490-1 conical log spiral antennas and their use has been called out in the Centaur EMC specification. Because of this, time was taken on a company funded R&D project to obtain standard gain figures on these antennas. Enclosed is a coverage of the procedure used in obtaining these measurements and some interesting developments concerning the usage of these antennas and the near and far field requirements.

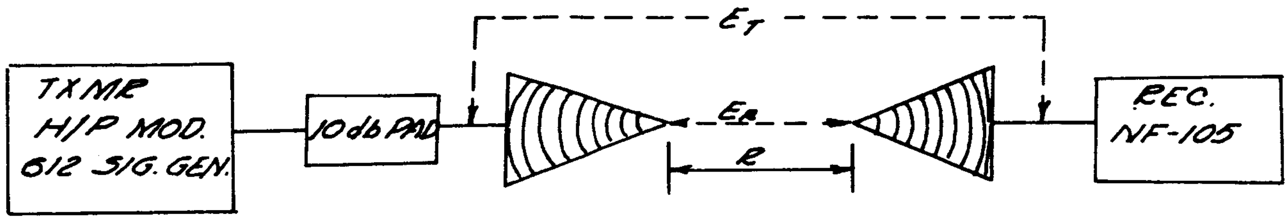
The type of antenna measured was the Stoddart 93490-1 conical log spiral antenna, frequency range 200 MHz to 1 GHz. A second unit covers the 1 to 10 GHz range. The type of measurement made to determine the gain was the "two antenna gain measurement procedure" in which both antennas are assumed to be identical. Figure 27(a) shows a test set up for the gain measurements.

$$G = \sqrt{G_1 G_2}$$

$$G = \frac{4\pi R}{\lambda} \sqrt{\frac{P_R}{P_T}} \qquad \sqrt{\frac{P_R}{P_r}} = \sqrt{\frac{\frac{E_R^2}{50}}{\frac{E_T^2}{50}}} = \frac{E_R}{E_T}$$

$$G = \frac{4\pi R}{\lambda} \frac{E_R}{E_T}$$

(a)



(b)

(c)

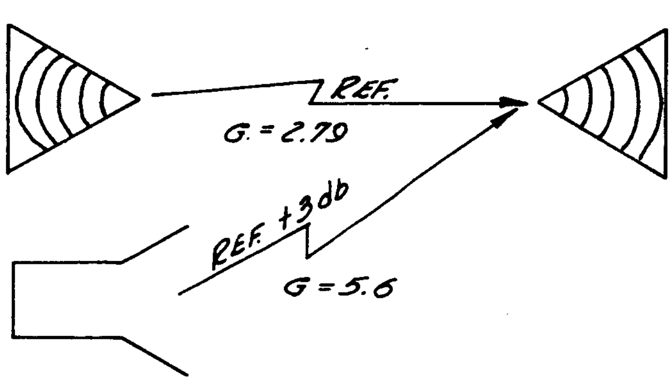


FIGURE 27 ANTENNA GAIN MEASUREMENTS

Where E_R and E_T are voltages measured at terminals of NF105 for transmitted and direct measurements.

In the use of the formula to determine the gain of two identical antennas strict attention has to be paid to the type of gain (G) referred to in the derivation of the formula. Referring to Figure 27(b) the power received, P_R, is

$$P_R = \frac{P_R G_T}{4\pi R^2} \quad \frac{\lambda^2}{4\pi} \quad G_R$$

where G_T and G_R are the power gains of the transmitting and receiving antennas, respectively. If $G_R = G_T$

$$G^2 = \left(\frac{4\pi R}{\lambda}\right)^2 \frac{P_R}{P_T}$$

$$G = \frac{4\pi R}{\lambda} \sqrt{\frac{P_R}{P_T}}$$

If P_R & P_T are both measured in a 50 ohm system

$$G = \frac{4\pi R}{\lambda} \quad \frac{E_R}{E_T}$$

It should be noted that G is still power gain even though it can be measured by a voltage ratio. The answer above will be a numeric associated with power gain, therefore

$$G\text{db} = 10 \text{ Log}_{10} \quad G = 10 \text{ Log} \frac{4\pi R}{\lambda} \quad \frac{E_R}{E_T}$$

Another way of viewing this is by the following development

$$P_R \sim G_1 \ G_2$$

If $\quad G_1 = G_2$

$$P_R \sim G^2$$

Since $\sqrt{P_R} \sim E_R \qquad E_R \sim G$ (Power Gain)

For the conical log spiral antennas (200 MHz to 1 GHz) the following gain measurements were made using the test set up of Figure 27(a). First E_R was measured via the transmission and reception of both conical antennas. Then the antennas were disconnected and a direct measurement was made of E_T via the same cable lengths used to connect to the antenna terminals. In the ratio of E_R/E_T the cable losses then cancel out.

$R = 11.1$ ft

@ 1 GHz $\frac{E_R}{E_T} = \frac{1}{50}$ $\lambda = 0.98$ ft.

$$G = \frac{4\pi R}{\lambda} \frac{E_R}{E_T} = \frac{142}{50} = 2.84$$

@ 800 MHz $\frac{E_R}{E_T} = \frac{1}{40}$ $\lambda = 1.23$ ft.

$$G = \frac{140}{40(1.23)} = 2.84$$

@ 600 MHz $\frac{E}{E} = \frac{1}{32}$ $\lambda = 1.64$ ft.

$$G = \frac{140}{1.64(32)} = 2.66$$

@ 450 MHz $\frac{E_R}{E_T} = \frac{1}{17.9}$ $\lambda = 2.18$ ft.

$$G = \frac{140}{(19.9)(2.18)} = 3.58$$

@ 300 MHz $\frac{E_R}{E_T} = \frac{1}{14}$ $\lambda = 3.28$

$$G = \frac{140}{(14)(3.28)} = 3.05$$

@ 200 MHz $\frac{E_R}{E_T} = \frac{1}{62}$ $\lambda = 4.92$ ft.

$$G = \frac{140}{(62)(4.92)} = 0.459$$

4.5.2 Three Horn Gain Determination. In order to check these figures of gain a three antenna measurement had to be made in which a standard gain horn antenna was substituted for one of the conical log spiral antennas at 1 GHz and the change in db of the voltage reading obtained had to check the difference between the gain of the conical log spiral antenna and the horn antenna. The gain of the std. gain horn was checked at 1 GHz using the test setup of Figure 27(a) at a distance of R = 25 ft. and found to be G = 5.6.

@ 1 HGz

The gain of the horn

$G_H = 5.6$ in db $G_H = 10 \text{ Log } 5.6 = 7.5$ db

The gain of the conical log spiral

$G_S = 2.79$ in db $G_S = 10 \text{ Log } 2.79 = 4.46$ db

The reading obtained by substituting the horn antenna for one of the spirals should have, thus, been $G_S + 3.04$ db and this was verified as seen in Figure 27(c).

4.5.3 Directivity and Effective Aperture. The Directivity of the conical log spiral can be calculated by the approximate formula

$$D = \frac{41253}{\phi_1^o \theta_1^o} = \frac{41253}{8100} = 5.1$$

Now if the maximum effective aperture A_{em} can be found, the linear dimension (d) for the $2d^2/\lambda$ far field criteria can be calculated. Another expression for D is

$$D = \frac{4\pi}{\lambda^2} A_{em}$$

@ 1 GHz $\lambda = 1$ ft and D from above is 5.1

$$A_{em} = \frac{D\lambda^2}{4\pi} = \frac{5.1}{12.6} = .405$$

To get d

$$\pi r^2 = A_{em} = .405$$

$$r^2 = .129$$

$$r = .36$$

$$d = .72 \text{ ft.}$$

applying the far field criteria

$$R = \frac{2d^2}{\lambda} = \frac{2(.72)^2}{1} = 1.04 \text{ ft.}$$

According to the calculations the far field zone for the conical log spiral antenna should begin at approximately 1 ft.

To check the above calculations the two Stoddard Antennas used in Figure 27(a) were moved consecutively closer to each other and gain calculations were made at each distance, the theory being that when gain changes are noted, near field affects are being encountered. These measurements were made at 1 GHz where the gain measured at 11.1 ft. was 2.79.

$$@\ 7.6 \text{ ft} \quad G = \frac{4\pi R}{\lambda} \quad \frac{E_R}{E_T} = \frac{4\pi(7.6)}{35} = 2.73$$

$$@\ 6.2 \text{ ft} \quad G = \frac{4\pi(6.2)}{20} = 3.9$$

$$@\ 4.3 \text{ ft} \quad G = \frac{4\pi(4.3)}{6.3} = 8.6$$

As can be seen the gain changes drastically between 4 and 6 feet indicating that the near field is much greater than 1 ft. as was indicated above.

Further investigations revealed that when considering end fire antennas such as the conical log spiral it is found that the far field criteria of $2(d)^2/\lambda$ does not necessarily hold due to the fact that the physical aperture is not easily defined. The wave is launched by currents arranged in phase such that the spacing between current carrying elements makes up for the phase difference in currents. The phase center of such a radiating system is hard to define. If the two antennas are of the same type, however, it is sometimes acceptable to use a criteria for the far field which uses the apertures of both antennas, i.e.

$$R \geq \frac{2(d_1 + d_2)^2}{\lambda}$$

where $d_1 + d_2$ = diameter based on A_{em} or

$$d = \frac{A_{em}}{\pi}$$

$$R \geq \frac{2(.72 + .72)^2}{\lambda} = 4.16 \text{ ft.}$$

This agrees more closely with measured values which show the near field is encountered between 4 and 6 ft.

The results of the above experimentation indicates that the gain of the conical log spiral antenna is better than that of the dipole in the same frequency range (G dipole = 1.64 numeric). However, when these antennas are used there may be some complaints that they are not as sensitive as the dipole antennas were. We have experienced this with our technicians performing screen room tests. Generally, this can be due to two factors, 1) placement of the antenna 2) the fact that the CLS antenna is directional, therefore, less likely to pick up all the reflections that obviously take place in a screened enclosure. The results obtained using the CLS antenna should be much more valid than those previously obtained with the dipole.

It should also be noted that the near field problem may dictate the reconsideration of how far away from the test sample this antenna should be placed. If this antenna is moved farther away from the test sample, however, there may be some problems encountered in small screened enclosures.

With the gain figures included herein corrections can be made to the calibration factors used with the dipole antennas thus making the CLS antenna useable for spec testing to radiated interference limits. We have just received the Stoddart high frequency CLS antennas (Model 93491-1). Similar gain measurements will be made to find the new calibration factors needed to make these antennas also useful for spec testing to radiated interference limits.

5. AUTOMATIC CHECKOUT OF EMC

It is recognized that the Marshall Space Flight Center's motivation in studying specifications for electromagentic compatibility is to arrive at overall compatibility in electromagnetic interference control ranging from the initial test of a component to the final automatic, checkout of all components assembled in the SATURN system.

This particular study addresses itself to what to measure and how to measure a component so that the data observed may be compared with data obtainable on a systems test thereby making conclusions of individual component compatibility directly transferrable to expected compatibility in the system. This dictates some desirable characteristics of procedures to be used. i.e.,

a. It is desirable to avoid any measurement that does not directly aid one in predicting compatibility in the assembled system.

b. It is desirable to measure parameters on the component level such that direct comparison may be made with a quantity measurable in the systems EMC test.

c. Finally this quantity measured in the system EMC test should be preferrably of a nature that it can be measured quickly and along with those quantities normally measured to accomplish the usual functional systems checkout thus establishing correct system functioning and electromagnetic compatibility simultaneously.

The consideration of compatibility between component and systems testing procedures and specification criteria is underway as apparent from the previous monthly reports and the earlier portions of this report.

While one cannot prescribe how to automate an EMC test before he has determined what he would measure and how he would measure parameters to establish compatibility, it is intended to consider the checkout problem first from a fundamental, conceptual point of view and later from the point of view of automating more specific compatib ility measurements arrived at in the course of this study. It is recognized, of course, that the actual implementation of automatic EMC testing for the SATURN V system is beyond the scope of this study.

5.1 A TENTATIVE APPROACH. Since one of the prime objectives of this study is to determine optimimum component level testing and since this determination is dependent on the ultimate use of the component level test data it is important that a basic concept of system testing be prescribed. A practical, currently used EMC system test procedure utilizes detector modules which are pre-set to susceptibility levels determined during component level EMC testing. A block diagram of such a test is shown in Figure 28. A system level EMC test is performed basically as follows: 1) test points on the vehicle are determined from component level testing, 2) the type of detector and treshold set of the detector is determined from component level test data plus an "assurance" or "probability factor (for example MIL-E-6051C states -6 db) if applicable, 3) the detectors are now connected into the system circuitry and the detector outputs are connected to a continuous events recorder, 4) a timing signal is also connected to the events recorder for data correlation, 5) if one of the pre-set levels on the detectors is exceeded, a 28 vdc pulse with a time duration of approximately 200 milliseconds is generated and sent to the events recorder, 6) the events recorder, at the end of the test, contains a history of all signal levels exceeding pre-determined susceptibility amplitudes, 7) the recordings are then manually compared to known events in an effort to determine the cause of the detected signals.

EMC testing as just described should be readily adaptable to Automatic Checkout Equipment (ACE). The detectors providing either a binary 1 or a binary 0, dependent on whether a susceptibility is present or not, should be compatible with existing digital technques. The use of detectors is important, since it is feasible to expect such a monitoring device will have dimensions of 1" x 2" x 3" or smaller. Such transducers could easily be flown with their outputs telemetered back. One modification to the detector, that is easily implemented, would be the capability of storing the detected state until a "destructive read" command is given either from the ACE or a Commutated Channel of telemetry. A block diagram of EMC Test using detectors and ACE is shown in Figure 29. The same figure is applicable to TLM usage by replacing ACE with TLM. Several conditions must be considered when developing such a system. A few of these are:

1. It will, in general, be a function of the ACE to read and reset the detector at a time compatible with operation.

2. In many instances a sequence of events of concern will span but a few seconds or minutes of the test sequence. In this case generally no monitoring would be done during the "dead time" and it would be required that the ACE send out an "arm" or "reset" command to assure that the detector is in the "ready state".

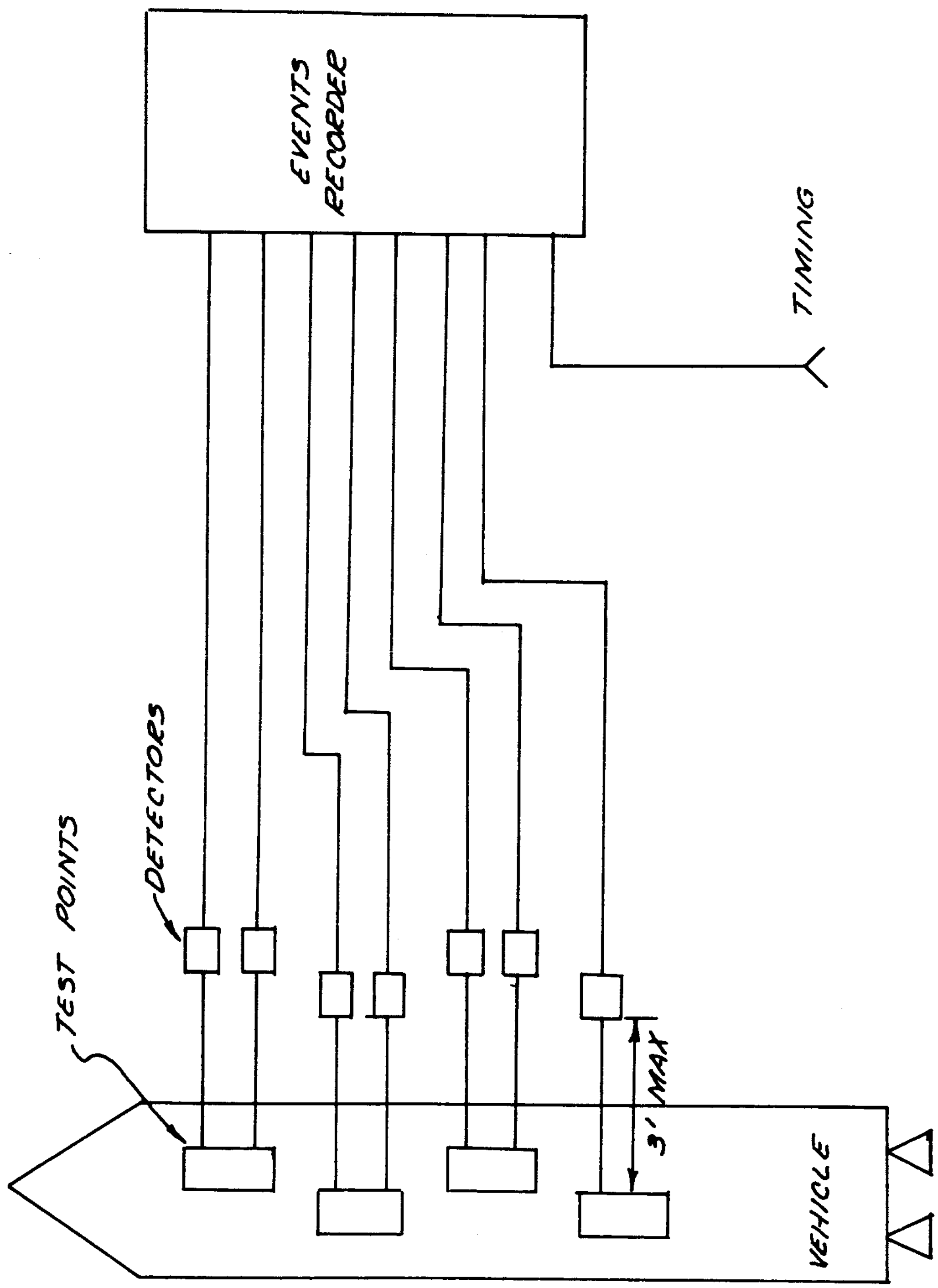


FIGURE 28 PRESENT CONFIGURATION FOR SYSTEM EMC TESTING

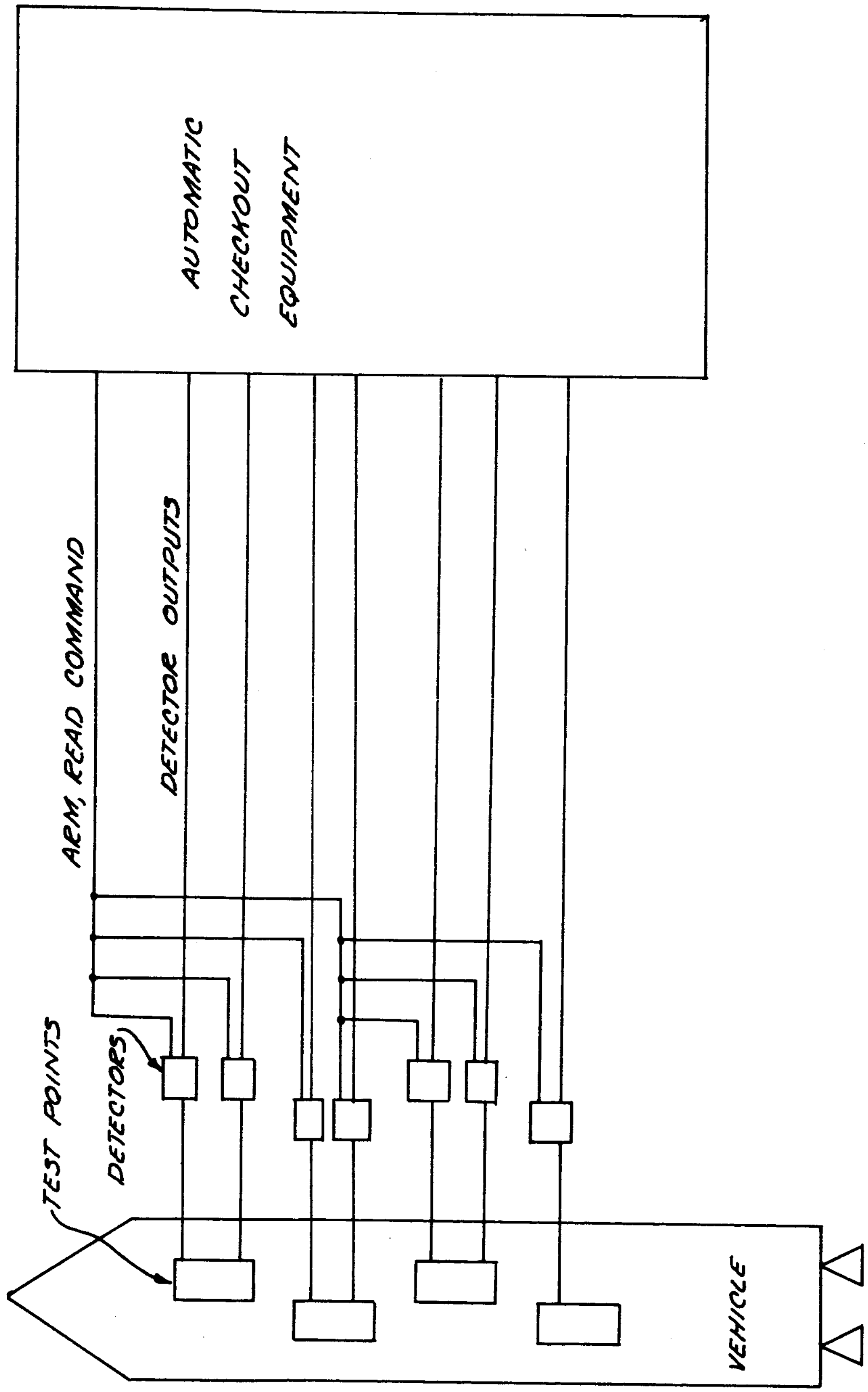


FIGURE 29 EMC TESTING IN CONJUNCTION WITH AUTOMATIC CHECKOUT EQUIPMENT

6. PLANS, PHASE II

6.1 GENERAL REMARKS. The work statement of Contract No. NAS8-11426, the monthly reports, and earlier sections of this report have adequately pointed out program goal, scope, and approach. It has been further pointed out that Phase I, though originally intended for familiarization, has been conducted as the beginning of studies originally planned to commence in Phase II which was to be the actual implementation of the intent of this study.

Phase II will still be to implement the intent of this study but is further along than would have been expected. Phase II will consist of definitization of individual topics required to be considered, continuation of the study of those topics already partially considered and reported herein, study of those awaiting consideration, and compilation of the final findings and recommendations to be transmitted to the Marshall Space Flight Center in fulfillment of Contract NAS8-11426.

The remarks following are not considered to be a complete definitization of all work remaining to be accomplished. But rather they indicate some specific areas to be continued or initiated upon receipt of go-ahead on Phase II.

6.2 SOME SPECIFIC REMARKS

6.2.1 Broadband Specification Limits. In the area of component level EMC tests broadband conducted measurements are made from 15 KHz to 25 MHz. (Marshall 279 Spec.) on power lines. In the same frequency range only CW susceptibility tests are performed so the question may well be asked, of what value is the data obtained from the broadband measurements from the standpoint of determining the EMC of the system. In other words, once the broadband data is collected, what can the levels of the EMI received be compared to in order to uncover possible problem areas. It would seem that the broadband measurements are made strictly to obtain some quality assurance, and from this standpoint the data appears to be useless in a systems EMC evaluation.

The only broadband susceptibility test performed on the component level is the transient or impulse susceptibility test. In the strict sense, however, this test has no relationship to the broadband measurement data collected. The susceptibility of the component under test is determined by the component response to the duration and/or amplitude of the impulse susceptibility test function. The measured broadband data taken on other components within the system vehicle which may affect the component under test is frequency domain data which cannot be correlated to the time/amplitude susceptibility test function used. The time/amplitude susceptibility test function can be converted to the frequency domain by a Fourier analysis but if the broadband susceptibility data is put in this form both measurement data and susceptibility data taken on component level tests are in a form which make it impossible to monitor the system in an automated fashion unless susceptibility bandwidths are previously known. It should be noted again here that in order to accomplish an EMC systems evaluation, the relevant measurements made on the component level tests are susceptibility measurements since these measurements establish the levels which can be monitored within the system during an automated EMC evaluation.

Since susceptibility levels have to be established on the component level in order to establish monitoring levels within the system a transient susceptibility test similar to that shown in MSFC Spec. 279 can be employed in which the component is subjected to transients of varying amplitudes and durations. An upper limit can be established for the transient amplitude and while this test is being performed the input of the package under test can be monitored using an oscilloscope to find the actual amplitude across the test terminals. During this test the type and amplitude of the interference being generated by the package under test can also be noted and compared to the level of the susceptibility test function. Limits for this interference relative to the susceptibility test function can be made so that the interference generated is far below that to which the package is subjected. If this is done to all components in the system, EMC criteria similar to that previously mentioned for CW tests can be employed. Data can then be in the form of oscilloscope photographs showing the amplitude of the test function used in the susceptibility test and the amplitude of the interference generated. The problem in broadband radiated measurements is much the same as that indicated for conducted broadband measurements except here determination has to be made concerning the possible redundancy of making these measurements. If 50 volt conducted transient susceptibility test functions are used to test packages it may be that the radiation emanating from this function will be far greater than any eminating for the operation of the package under test. This will be the subject of further investigation during phase II of this study.

6.2.2 Further Comparison of Radiated and Line Conducted Susceptibility Tests. Another consideration during the next period of study will be the extension of line radiation vs. dipole radiation for CW tests below 150 Kc. During this period of study, investigations showed that line radiations due to placing CW test functions on power lines probably are more effective than dipole radiated susceptibility functions in the 150 KHz to 400 MHz frequency range.

6.2.3 Continuation of Study of CW Conducted Susceptibility. During this study period the feasibility of replacing CW susceptibility tests with a transient test which would check both CW and broadband susceptibility was mentioned. During the next study period experimentation will be performed to verify the feasibility of using this test technique.

6.2.4 Study of Magnetic Susceptibility Testing. Another area which should be covered in the next study period is that of low frequency magnetic field susceptibility. The MSFC 279 specification calls out radiated susceptibility measurements in the .15 MHz to 10 GHz frequency range (over at least part of this frequency range this test may be redundant because of power line conducted tests) but below .15 MHz consideration is not given to the possibility of case penetration by low frequency magnetic fields. The 60 Hz and 400 Hz tests performed are concentrated around power lines and may be redundant due to conducted susceptibility tests which cover the same frequency range. The power line conducted susceptibility test may also prove to produce magnetic field intensities great enough to eliminate the need for magnetic susceptibility tests but experimentation should be performed to prove this.

6.2.5 Extension of Conducted Susceptibility to Signal Lines. Thus far attention has been paid to radiated and conducted measurements. The conducted measurements (susceptibility and measured EMI) have been confined to power line measurements. During the next study period criteria for signal line measurements will also have to be made. This criteria will have its basis in susceptibility testing since threshold levels of signal circuits have to be found in order to make meaningful measurements in the system. Once these levels are established a type of signal to noise criteria can be established based on signal threshold levels.

6.2.6 Consideration of the Relation Between CW and Broadband Tests. Initial investigations of older Military Specifications have shown that the difference between CW and BB interference limits may be related to the impulse bandwidth of the receiver that was orginally used to set up these limits. This should be further investigated because if it is true that this is the case it may be possible to use one specification limit for both BB and CW measurements and specify the impulse bandwidth of the receiver used to make the measurements. This would represent a large savings in test time for qualification testing to present interference limits.

6.2.7 High RF Ambient Environment. Another area that will be covered during the next study period will be the effects of a high ambient RF environment. It is presently felt that if high level susceptibility test functions are used, the environment into which the test sample is placed will not be of an amplitude equal to that to which the test sample has already been subjected. Analysis and experimentation can be used to prove this point.

APPENDIX I: MANPOWER

The detailed expenditures against Contract No. NAS8-11426 have been reported monthly on NASA Form 533. In addition the monthly technical reports have indicated the manpower level employed. Figures 30 and 31 show the man-hour usage and manning level respectively. Phase I has been accomplished employing an average of approximately 2.5 men. Phase II will be accomplished with an average of approximately 4 men. This level is believed compatible with the Phase II task which will reflect more experimental work and is possible within the funds available.

GD/A
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CONTRACT NO. NAS8-11426
27 NOVEMBER 1964

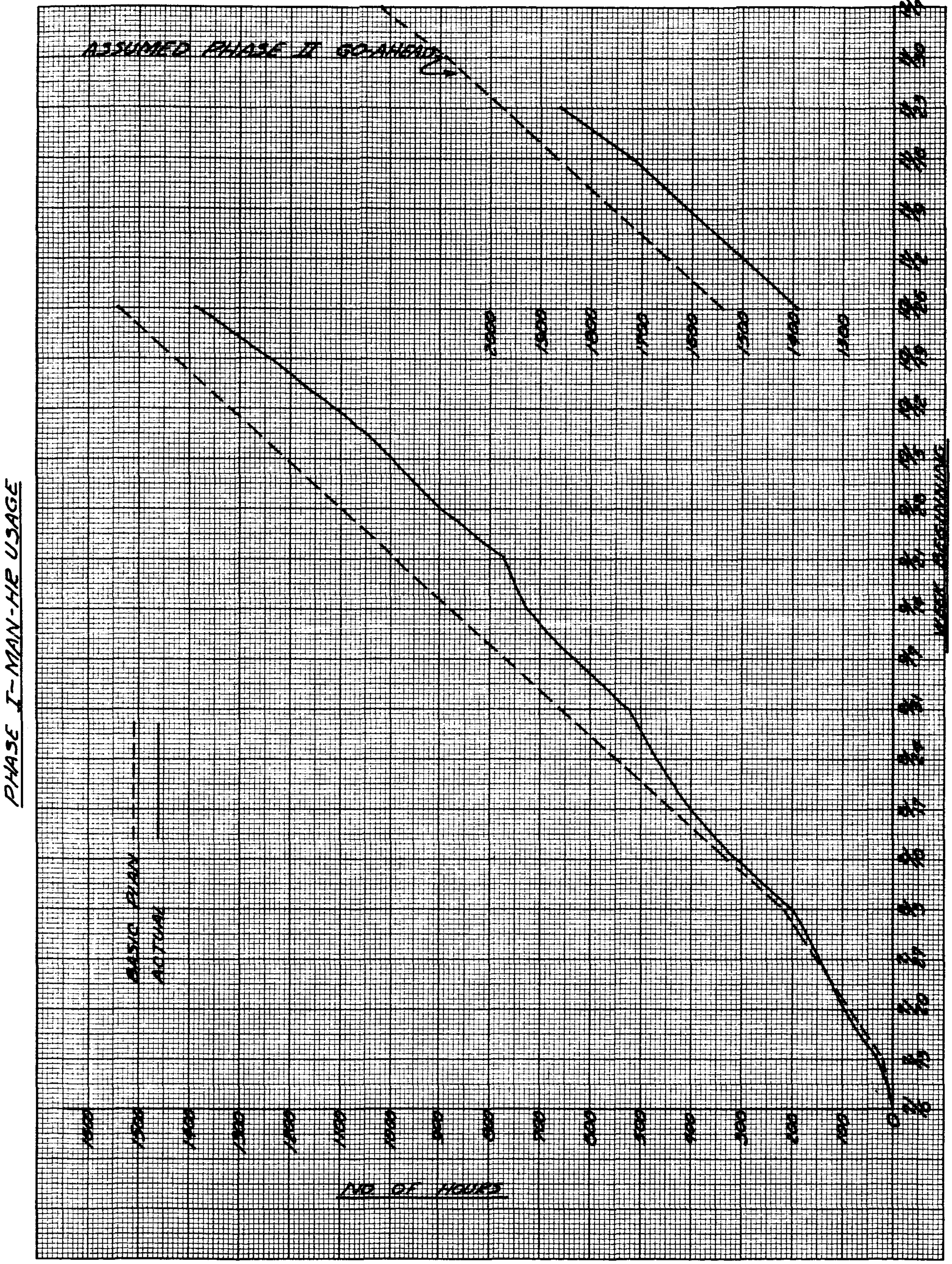

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FIGURE 30 PHASE I MAN-HOUR USAGE

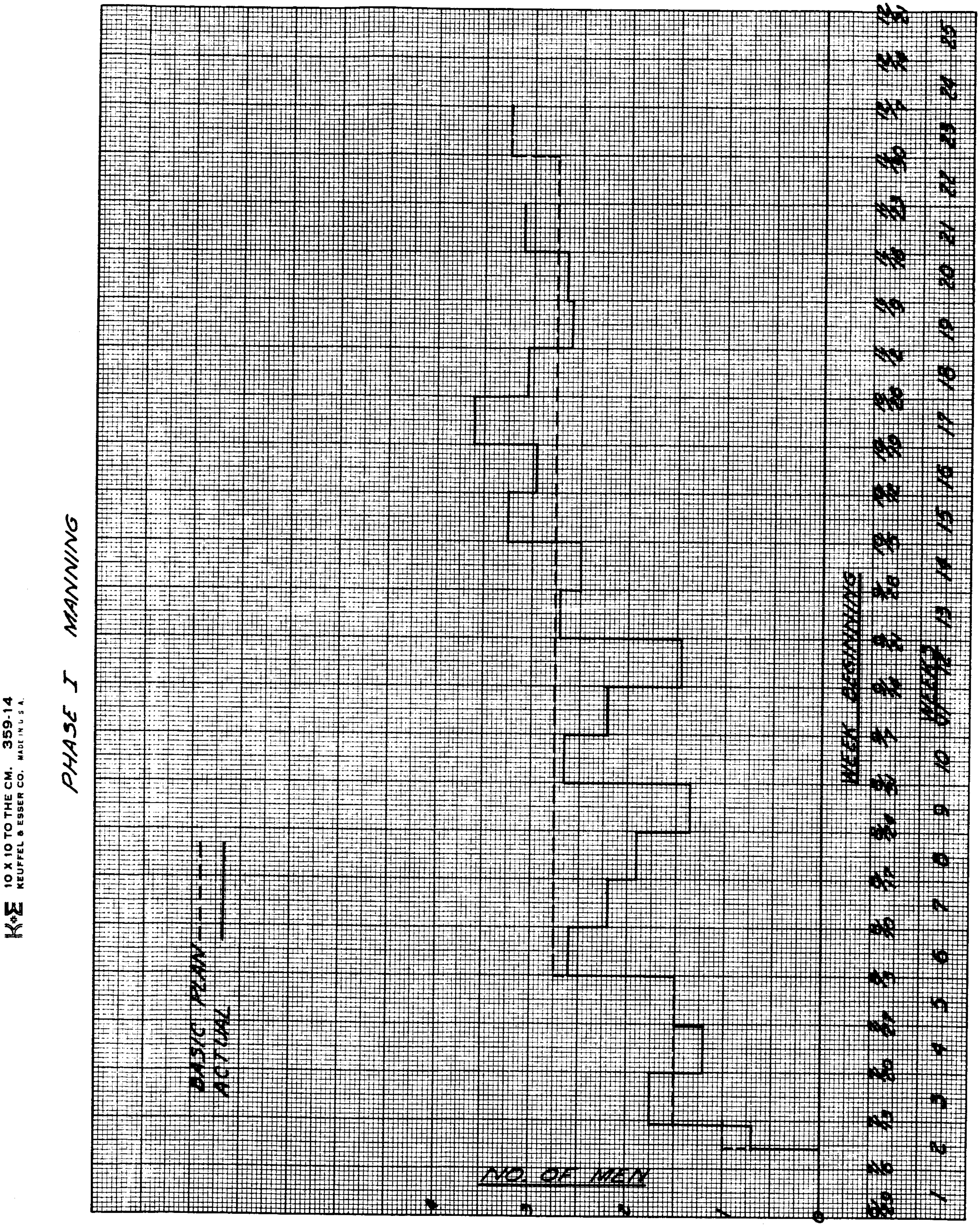

FIGURE 31 PHASE I MANNING LEVEL

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